GROUND–WATER/SURFACE WATER INVESTIGATION PLAN PHASE 1 REMEDIAL INVESTIGATION FINAL REPORT

Volume 1 of 5

June 7, 1991

Prepared for:

Industri-Plex Site Remedial Trust
36 Commerce Way
Woburn, Massachusetts

Prepared by:

**Roux Associates, Inc.
Environmental Science and Engineering, Inc.
PTI Environmental Services**

LETTER OF TRANSMITTAL

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TO Mr. Joseph DeCola

U.S.E.P.A.

DATE June 7, 1991

SUBJECT Industri-Plex Site, Woburn, MA

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BY *Martha M. Smith*

June 7, 1991

Mr. Joseph DeCola
Remedial Project Manager
United States Environmental
 Protection Agency, Region I
Waste Management Division
J.F.K. Federal Building HRS-CAN-3
Boston, Massachusetts 02203-2211

Dear Mr. DeCola:

On behalf of the Industri-Plex Site Remedial Trust, we are submitting the attached Ground-Water/Surface-Water Investigation Plan Phase 1 Remedial Investigation Final Report for the Industri-Plex Site in Woburn, Massachusetts. This report is being submitted in accordance with the Consent Decree and the Ground-Water/Surface-Water Investigation Plan reporting requirements.

Please contact me if you have any questions.

Very truly yours,

Timothy G. Baumann
Principal Scientist/Project Manager

Enclosure

cc: J. Naparstek, MDEP
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1.0 INTRODUCTION

The Ground-Water/Surface-Water Investigation Plan (GSIP) Remedial Investigation (RI) was initiated by Roux Associates, Inc. (Roux Associates), Environmental Science and Engineering, Inc. (ESE), and PTI Environmental Services (PTI) for the Industri-Plex Site Remedial Trust (ISRT) in March 1990 and completed during January 1991. The GSIP RI was performed according to the procedures outlined in the GSIP RI Work Plan (Roux Associates Inc., December 21, 1989) and the requirements of the Consent Decree (CD) between the United States Environmental Protection Agency (USEPA) and the ISRT. The CD was negotiated and executed by the parties involved (USEPA, the Commonwealth of Massachusetts, and the Settlers) in order to avoid protracted litigation (United States District Court, 1989). The work to be implemented under the CD will provide for containment and/or treatment of hazardous substances in the soils, air, and ground water at the Site in a manner consistent with the Record of Decision (ROD). The Consent Decree provides for the responsible parties to assume the costs of the present remedial activities, and also provides for the financing of any necessary future remedial activities. Completion of the GSIP RI and submittal of the RI report to the USEPA fulfills a major requirement of the CD.

The GSIP RI was performed in response to sections 106 and 107 of the Comprehensive Environmental Response, Compensation and Liability Act (CERCLA), 42 U.S.C. ss 9606, 9607, and Section 7003 of the Solid Waste Disposal Act (SWDA) 42 U.S.C. ss 6937; and the Massachusetts Oil and Hazardous Material Release Prevention and Response Act, Massachusetts G.L. c. 21E, the Massachusetts Hazardous Waste Management Act, G.L. c. 21C, the Massachusetts Clean Water Act, Massachusetts G.L. c. ss 27 (14), and the Massachusetts Solid Waste Management Act, G.L. c. 21H. The USEPA, the Commonwealth of Massachusetts, and the ISRT entered into the CD under requirements of Section 122 (d) (2) of CERCLA and 28 C.F.R. ss 50.7.

The GSIP RI Study Area is located approximately 10 miles north of Boston, Massachusetts. The Study Area encompasses the 245-acre Industri-Plex Site (Site) and contiguous areas shown on Figure 1.

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1.1 Purpose of Report

The purpose of this report is to present results of the RI and to provide all information necessary to support development of the applicable remedial alternatives (as defined in the GSIP RI Work Plan) during the Feasibility Study (FS). Results of the Pre-Design Investigation (PDI) performed by Golder Associates, Inc. (Golder) are integrated with results of the GSIP RI and are presented in this report where appropriate.

1.2 Site Background

The Site is located in an industrial park in the northwest corner of Woburn, Massachusetts, near the intersection of two major highways, Route 93 and Route 128. The 245-acre Site is dissected by the Aberjona River and its tributaries, including Hall's Brook, which discharge to the Mystic River.

From 1853 to 1863 the Woburn Chemical Company operated on the Site. In 1863 the Merrimac Manufacturing Company (Merrimac) purchased the Woburn Chemical Company and merged into the Merrimac Chemical Company. The Merrimac Chemical Company produced sulfuric acid and other chemicals for use in local textile mills, and the leather and paper industries. Merrimac was also the largest producer of arsenic pesticides in the United States during this period.

In 1915 Merrimac established a subsidiary, the New England Manufacturing Company which produced organic chemicals. In 1929 Merrimac was purchased by Monsanto Chemical Company and all Merrimac chemical operations were terminated by 1931.

In 1934 the property was sold to the New England Chemical Company. New England Chemical Company constructed and operated a glue manufacturing plant which was subsequently purchased by Consolidated Chemical Company in 1936, and then by Stauffer Chemical Company in the late 1950s. Stauffer Chemical Company (Stauffer) operated the glue plant until 1969.

The glue manufacturing process utilized raw animal hides and water-chrome-tanned hides from local leather manufacturers and produced glue by boiling them in vats and then concentrating the extract through evaporation and drying. Sodium hydroxide, sulfuric acid,

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and magnesium carbonate were used to speed the extraction process. Hide residues from the extraction process were buried in pits on the property. Wastewater from the washing and disinfecting processes was sent first to a settling lagoon to remove suspended solids and grease, and then to the municipal sewer system.

In 1969 Stauffer sold about 149 acres of the property to the Mark Phillip Trust and the remaining 35 acres were sold to others. In the 1970s Mark Phillip Trust began developing the Site for further industrial use. Excavation activities during this development created noxious odors, and nearby residents registered complaints. In 1979 the USEPA obtained a court order to stop further development activities, and in 1981 the Site was listed on the Superfund Interim List of 115 Top Priority Hazardous Waste Sites.

On May 25, 1982, the USEPA and the Massachusetts Department of Environmental Quality Engineering (DEQE) signed a Consent Agreement with Stauffer Chemical Company requiring Stauffer to undertake a site investigation and recommend a remedial action.

In 1983, Phase 1 of a Remedial Investigation (RI) was completed by Stauffer Chemical Company. The study defined the areal extent of the waste deposits, determined the chemical composition of the waste, and measured concentrations of organic compounds and metals in the ground water. The Phase 2 (RI) subsurface investigation, conducted by Roux Associates during 1983, further delineated the extent of inorganic and organic compounds at the Site. Roux Associates modeled movement of the plume of benzene and toluene in the ground water and concluded that the presence of the two compounds in the aquifer was due to unauthorized disposal, probably after 1969.

Malcolm Pirnie conducted a FS for the Site, and in 1985 recommended that remedial action consist of pumping ground water at the Site boundary, treating it and discharging it to surface water, capping the East Hide Pile and collecting and treating the emitted gases, and capping all other areas of potential direct contact.

The ROD for the Industri-Plex Site was issued by USEPA Region 1 on September 30, 1986 and the CD covering implementation of the remedy was entered by the U.S. District Court on April 24, 1989. The remedy for soils containing metals above action levels is installation

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of a permeable cover consisting of a geotextile barrier and 16 inches of clean soil. This cover will extend over most of the Site west of Commerce Way. Sediments with metal concentrations above action levels will be removed by dredging unless they contain odorous substances. Odorous substances are present in most of the surface-water bodies and drainways on-site and they will be remediated by the installation of a cover (e.g. Lower South Pond), installation of concrete channel liners (e.g. 1-93 Drainway) or culverts (e.g. West Branch of the Aberjona River). An impermeable cover will be installed on the East Hide Pile to collect odorous gases. These gases will be routed to a shrouded flare for thermal oxidation.

The interim remedial action for ground water is a pump and treat system. Four hydraulic barrier wells will be installed along Boston Edison Right of Way Number 9 to control downgradient migration of VOC and metal-containing ground water. A total of three "hot spot" recovery wells will be installed. Two wells will be located in the benzene/toluene plume originating near the intersection of Commerce Way and Atlantic Avenue. One well will be installed in the arsenic/chromium plume migrating away from the West Hide Pile. The recovered ground water will be treated to remove odors, metals and organic constituents and routed to a ground-water recharge basin equipped with a surface-water overflow. A ground-water monitoring program will be developed and implemented to determine the effectiveness of the ground-water extraction system.

The PDI was performed by Golder Associates Inc. from 1990 through 1991 to develop site-specific data necessary to support design of the remedy specified in the CD. Data obtained during the PDI focused on determination of the extent of hazardous substances in soils, sediments, and surface water; geotechnical data needs relating to the capping of the hide piles and the interim ground-water remedy (pump and treat); performance of a baseline air survey; hide pile gas treatability; and sediment/wetland remediation. Results of the PDI were summarized in a report titled "Pre-Design Investigation Final Report, Industri-Plex Site, Woburn, Massachusetts" submitted to the USEPA and the Massachusetts Department of Environmental Protection (MDEP) during April 1991 (Golder Associates, Inc., 1991).

The Remedial Design (RD) program was initiated during 1990 by Golder Associates Inc. The Preliminary Design Report (PDR) was submitted to the USEPA and the MDEP on October 1, 1990. The Preliminary Design Report (30 percent design) Response to Comments

document was submitted to the USEPA and the MDEP on January 21, 1991. Additional site investigations were performed to develop hydrogeological information necessary for a preliminary extraction system design which is presented in the 30 Percent Design Supplement Report submitted on February 14, 1991 (Golder Associates, Inc., 1991).

The 60 Percent Design Report was submitted to the USEPA and the MDEP during April 1991 (Golder Associates, Inc., 1991). The 60 Percent Design Report provides additional engineering design details regarding the ground-water extraction, surface-water management, permeable cover design, streams and wetlands remediation, and hide pile gas collection and treatment system.

1.3 Report Organization

This RI report is organized according to the format proposed in the GSIP RI Work Plan which is consistent with "Guidance for Conducting Remedial Investigations and Feasibility Studies Under CERCLA". Results of the ground-water, surface-water, and stream-sediment investigations are presented in Sections 3.2 through 3.4, respectively. Results of the metals mobility study are discussed in Section 3.5, and the risk assessment is presented in Section 4.0. A summary of RI results and conclusions relative to objectives of the GSIP RI are provided in Section 5.0.

All field activities were performed in accordance with requirements of the GSIP RI Work Plan and Roux Associates Standard Operating Procedures (SOPs). The SOPs and field change documentation (approved by the USEPA) are provided in Appendix A. All supporting documentation is provided in the appendices (Appendices B through G) and depicted on Plates (Plates 1 through 23). In addition, data are summarized in tables (Tables 3-1 to 3-29, and 4-1 to 4-48), figures (Figures 1 through 57) and in overlays (Overlay 1 through 4) to convey an understanding of hydrogeological conditions and the extent of inorganic and organic compounds in the media studied. The ground-water (GSIP RI and PDI), surface-water and stream-sediment data are provided as a dBase III+ file on disk at the end of Volume 1.

2.0 STUDY AREA INVESTIGATIONS

Objectives of the GSIP RI are outlined below.

- Define ground-water, surface-water and sediment quality coming onto the Site.
- Define ground-water, surface-water and sediment quality leaving the Site.
- Determine potential impacts of constituents released on-site to downgradient water use, based on the results of the above objectives.
- Determine if metals could become mobile in the future and, if so, what risks they represent to human health and the environment.

2.1 Ground-Water Investigation

As outlined in the GSIP RI Work Plan (page H-2), objectives of data collection efforts for the ground-water investigation were to provide site-specific information that can be incorporated by the USEPA into the MSGWRP required in the September 1986 ROD. The scope of the ground-water investigation described in the GSIP RI Work Plan is consistent with objectives of the MSGWRP, which includes the following:

- to evaluate on-site and off-site conditions;
- to identify and characterize possible source areas; and
- to define the upgradient aquifer conditions influencing ground-water quality in the portion of the aquifer investigated during the Stauffer study (Stauffer, 1983).

Specific tasks that were performed to achieve these objectives are outlined below.

- Installed three additional observation wells.
- Measured water levels in all on-site wells and surface-water staff gauges, and constructed a ground-water elevation and flow direction map using surface-water elevation data.
- Collected ground-water samples for water quality analysis from new and existing wells.
- Determined chemical forms of arsenic, lead, chromium, and mercury.
- Evaluated the interrelationship of ground water and surface water/sediment.
- Developed a more complete understanding of the aquifer.

As outlined in the GSIP RI Work Plan, results of these investigations will provide site-specific information which can be incorporated in the MSGWRP as required by the September 1986 ROD.

2.2 Surface-Water/Stream-Sediment Investigation

The objective of the surface-water and stream-sediment investigation, as defined in the GSIP RI Work Plan, was to evaluate the extent and characteristics of metals and organics in the surface drainage system on-site and in surrounding upgradient and downgradient areas of the drainage basin within the Study Area. This objective is consistent with objectives of the MSGWRP.

The following tasks were performed to achieve these objectives.

- Sampled surface water (dissolved and total) and sediment at 17 location for analyses of selected metals and organic compounds.
- Sampled and analyzed water and sediments at two locations in each trunk sewer line passing through the Site.
- Measured stream flow, rate, and volume at each sampling location.
- Inventoried existing discharges.

2.3 Metals Mobility Study

The objective of the metals mobility study as outlined in the GSIP RI Work Plan (page H-1) was to identify the factors that govern the mobility of arsenic, chromium, lead, and mercury at the Site. The following tasks were performed to achieve this objective.

- Determined the environmental mobility and fate of arsenic, chromium, lead, and mercury through evaluation of the literature.
- Evaluated the existing arsenic, chromium, lead, and mercury database.
- Identified and measured the critical chemical and physical parameters controlling the mobility of arsenic, chromium, lead and mercury in ground water.
- Determined the chemical species of arsenic, chromium, lead, and mercury present in ground water at the Site.
- Evaluated the current and future mobility of arsenic, chromium, lead, and mercury based on information obtained during execution of the tasks described above.

2.4 Human Health Evaluation/Ecological Evaluation

The scope and objectives of the human health and ecological evaluations are outlined in the following sections.

2.4.1 Human Health Evaluation

The objective of the human health risk assessment was to determine the extent to which ground-water and surface-water conditions, as delineated during the GSIP RI and the PDI, may affect human health, welfare, or the environment.

The findings of this study will be used to assess whether further remedial action is required at the Site. If a determination is made that further remediation is necessary, the health risk data developed during this study will form a basis for determining the extent of remediation that must be performed to address human health concerns.

The human health risk assessment was developed in accordance with the USEPA guidance documents listed below.

- "Risk Assessment Guidance for Superfund" (USEPA, 1989c).
- "Supplemental Risk Assessment Guidance for the Superfund Program" (USEPA, 1989a).
- "Superfund Exposure Assessment Manual" (USEPA, 1988).
- "Exposure Factors Handbook" (USEPA, 1989d).
- "Guidance for Conducting Remedial Investigations and Feasibility Studies Under CERCLA" (USEPA, 1988).
- "Guidance for Disposal: Site Risk Characterization and Related Phase 2 Activities" (MDEP, 1989).
- Health Effects Assessment Summary Tables (HEAST, 1991).

Current toxicity information was obtained from these documents and verified using available computer-based toxicity files (IRIS, RTECS). Media concentrations, of the various constituents of concern, required to conduct the human health risk assessment were collected during the GSIP RI and the PDI.

The risk assessment includes the following general components:

- Hazard Identification;
- Dose-Response Assessment;
- Exposure Assessment; and
- Risk Characterization.

2.4.2 Ecological Evaluation

The objectives of the ecological evaluation were to:

- identify the types of habitats, organisms, and communities on or around the Site;
- evaluate the nature and extent of organic and inorganic compounds at the Site; and
- determine if there is an adverse (or beneficial) relationship between the above two elements.

The ecological evaluation was performed in accordance with the structure and methodologies outlined in the following USEPA guidance documents.

- "Biological Field and Laboratory Methods for Measuring the Quality of Surface Waters and Effluents" (USEPA, 1973).
- "Water Quality Assessment: A Screening Procedure for Toxic and Conventional Pollutants" (USEPA, 1982).
- "Quality Criteria for Water". Office of Water Regulations and Standards, Washington, D.C. (USEPA, 1986a).
- "Ecological Assessment of Hazardous Waste Site: A Field and Laboratory Reference" (USEPA, 1989b).
- "Risk Assessment Guidance for Superfund. Volume II: Environmental Evaluation Manual" (USEPA, 1989e).
- "Standard Methods for the Examination of Water and Wastewater" (APHA, 1980).
- "User's Manual for Ecological Risk Assessment" (ORNL, 1986).

3.0 RESULTS OF THE RI INVESTIGATION

The GSIP RI field investigation was performed from March 1990 through September 1991. The results of the field investigation were evaluated along with the data developed during the PDI to characterize the nature and extent of inorganic and organic compounds in ground water, surface water and stream sediments. These data were used to evaluate the mobility of metals within the Study Area and to perform a human health evaluation and ecological evaluation. The results of the field investigation, including the metals mobility study, are summarized in the following sections (3.2 through 3.4). The results of the human health evaluation and ecological evaluation are presented in Section 4.0.

3.1 Applicable or Relevant and Appropriate Requirements

As part of the evaluation of Applicable or Relevant and Appropriate Requirements (ARARs) the following promulgated state and federal standards and regulations were identified.

Federal	State
Safe Drinking Water Act	Safe Drinking Water Act
National Primary Drinking Water Standards	Clean Waters Act
National Secondary Drinking Water Standards	Groundwater Standards
Clean Water Act	Wetlands Protection Act
Ambient Water Quality Criteria	Water Quality Standards
Toxic Pollutant Effluent Standards	Regulations for Control of Air Pollution
Executive Order on Flood Plain Management	
Executive Order on Wetlands	
Resource Conservation and Recovery Act	
Clean Air Act	

The evaluation of ARARs will be finalized during the performance of the FS and presented in the FS report.

3.2 Ground-Water Investigation

The GSIP ground-water investigation was performed to determine the relationship between ground water and surface water, and the nature and extent of inorganic and organic compounds in the unconsolidated aquifer. The unconsolidated aquifer consists of the saturated sand and gravel deposits (with occasional fine-grained materials [i.e., silts]) that overlie the crystalline bedrock and/or till deposits within the Study Area. These unconsolidated materials were deposited in low, buried valleys incised into the crystalline bedrock.

Briefly, the buried valleys consist of two minor buried valleys, one whose axis trends northeast to southwest approximately coincident with a line extending from the vicinity of Recharge Test Borings RB-12 and RB-13, through Observation Well OW-16, towards Observation Wells OW-17 and OW-42. A second minor valley has an axis which trends almost north to south, approximately coincident with a line projected between the East and West Hide Piles, through the area between Observation Wells OW-36 and OW-37, to and along the Massachusetts Bay Transportation Authority (MBTA) railroad tracks to Observation Well OW-14, towards Observation Wells OW-17 and OW-42 (Plate 5 and Overlay 1). At the confluence of these two minor valleys (i.e., the area around Observation Wells OW-17 and OW-42), the major valley continues to extend in a north to south direction, through the area between Observation Well Clusters OW-24A/OW-24B and OW-19/OW-19A, through Observation Wells OW-33A and OW-33B, towards Observation Wells OW-27A and OW-27B (Plate 5 and Overlay 1).

Thus, the ground-water data developed during the PDI (Tasks GW-1; Delineation of the Aquifer and GW-2; Hydrogeologic Characterization [Roux Associates, Inc., 1991 and 1990c, respectively], and the Slug Test Report [Golder Associates, Inc., 1991a]) and the 60 Percent Design Report (Golder Associates, Inc., 1991b) were completely incorporated into the GSIP RI ground-water investigation report as discussed above, and as summarized in the following sections.

3.2.1 Evaluation of the Relationship Between Ground-Water and Surface Water

The relationship between ground water and surface water was investigated to characterize flow through the aquifer and the recharge/discharge relationships between the aquifer (ground-water flow) and the surface-water bodies (i.e., the Aberjona River and Hall's Brook). Information obtained on these correlations was then used to assist in understanding the

transport of inorganic and organic compounds within the Study Area. An understanding of ground-water/surface-water relationships was determined through the concurrent measurement of ground-water and surface-water elevations, and the continuous measurement of ground-water elevations in two piezometers (PZ-1 and PZ-2) and the adjacent surface-water body (Aberjona River).

Water levels were initially measured in all observation wells on eight occasions over a 6-month period (i.e., April 10, 1990 through September 26, 1990), and followed-up by three additional rounds of water-level measurements taken on December 7, 1990, February 26, 1991, April 17 to 19, 1991, and May 13, 1991 (Table 3-5). In addition, surface-water elevations were measured concurrently (with the exception of December 7, 1990 and April 17 to 19, 1991) at surface-water sampling locations SW-1, SW-3, SW-7, and SW-14, using staff gauges (Table 3-11). The water-level data from April 10, 1990 (high-flow surface-water sampling conditions, Plate 8) and August 13, 1990 (low-flow surface-water sampling conditions, Plate 9) were contoured to depict ground-water flow directions and the relationship between ground-water and surface-water elevations.

Based upon the ground-water and surface-water level data presented in Plates 8 and 9, and Figure 2, the surface-water drainages present within the Study Area are predominately gaining streams, (a stream or reach of a stream is gaining when the flow is being increased by the inflow of ground water [Fetter, Jr., 1980]). As evidenced on Plates 8 and 9 and Figure 3, equipotential lines (lines of equal total hydraulic head [Fetter, Jr. 1980) are deflected by the streams such that flow lines display shallow ground water flowing towards, and discharging into, the streams. (In the context of this report, the term "shallow," when used in conjunction with "ground water" or "aquifer," signifies ground water at approximately the same depth below the water-table surface as the depth of the bottom of the stream [i.e., the streambed].) Conceptualized models of this ground-water/surface-water interaction are illustrated in Figures 3 and 4, which will be discussed in detail in Section 3.2.2.8.

A detailed understanding of the relationship of ground water to surface water on-site was determined through collection of continuous water-level measurements at Piezometers PZ-1

and PZ-2, and the Aberjona River. The relationship of the piezometers to the Aberjona River is presented in Figure 5. Piezometer PZ-1 was located 25 feet (ft) and PZ-2 was located 50 feet from the Aberjona River to provide a profile of the water-table and the surface-water elevations.

Each piezometer was constructed with a 10-ft long screen to allow for water-table fluctuations, which were on the order of several feet (i.e., attaining a maximum of almost 4 ft for the period of record [Plate 10]). Although the screen lengths of the piezometers are greater than the depth of the Aberjona River (for the reasons discussed below), ground-water elevations are representative of aquifer conditions adjacent to the stream, as evidenced in the excellent correlation between ground-water and surface-water elevations illustrated on Plate 10.

As illustrated in Figure 5, Piezometer PZ-1 is screened across a section of sediments ranging from gravel to clay (i.e., coarse-grained to fine-grained), interbedded with some peat and hides, and Piezometer PZ-2 is screened across a silty sand zone. It is evident from Figure 5 that the lithology changes rapidly over a short distance (e.g. the 25-ft distance between Piezometers PZ-1 and PZ-2), and the aquifer matrix within the area along the Aberjona River, where discharge and recharge relationships between the aquifer and the river were investigated, is also likely to change with distance.

As presented in the subsequent discussion on, and calculation of, ground-water flow (flux) into the Aberjona River from the aquifer, this geologic variability was taken into account in order to provide an estimate of the range of flux into the Aberjona River. This was accomplished by using a hydraulic conductivity from published and field data that is representative of the general lithology of the area through which the flux was calculated, and using a range in the hydraulic gradients between ground-water elevations measured in Piezometer PZ-1 and surface-water elevations measured in the Aberjona River.

Elevations of the ground water in Piezometers PZ-1 and PZ-2 are consistently higher than the surface-water level in the Aberjona River, which indicates that shallow ground-water flow is towards, and into, the Aberjona River (gaining stream) from April 1990 through November 1990 (Plate 10). The only periods when this relationship is reversed is during rainfall and

associated high runoff events (i.e., July 25, August 12, and October 14, 1990), when surface-water flow was from the Aberjona River into the water-table aquifer. However, as indicated by the data base (Plate 10), these are short-term events, and the Aberjona River is characteristic of a gaining stream.

Water-level data obtained from synoptic and continuous measurements during the GSIP indicate that shallow ground water discharged to surface water during the period of measurement (April 1990 through May 1991) except during rainfall and runoff events. This relationship is apparently maintained throughout seasonal changes in precipitation, as illustrated on Plates 8 and 9, and Figure 2, which depict water-table maps on April 10, 1990, August 13, 1990, and May 13, 1991, respectively, and as provided in Table 3-5 which provides water-elevation data from April 10, 1990 to May 13, 1991. Although the magnitude of the heads in the flow system differ, the direction of ground-water flow remains essentially the same with shallow flow towards and into the streams. This finding implies that where gaining surface-water drainages intercept shallow ground-water (i.e., ground water at approximately a depth equivalent to the stream bottom) containing inorganic and organic compounds, these compounds are likely to discharge to surface water.

Additional information was developed regarding the relationship between surface water and ground water during the performance of the PDI. The constant-rate (pumping) test results indicated that in the area of the unconsolidated, water-table aquifer where the test was performed (south of Digital Equipment Corporation), Hall's Brook is a recharge (induced-infiltration) boundary to the aquifer. This was evidenced in the water levels measured and plotted for Temporary Well TW-5, which showed that the drawdown in Temporary Well TW-5 decreased and flattened as surface water infiltrated through Hall's Brook stream bed into the cone of drawdown created by Pumping Well PW-1 (Roux Associates, Inc., 1990b). However, Hall's Brook is not a constant-head boundary because the brook only penetrates a few feet (e.g. approximately 3 ft in the test area) into the total saturated thickness of the water-table aquifer (e.g. approximately 40 ft to 60 ft in the test area) (Plate 5).

An estimate of the flux of ground water discharging to the surface-water body (between Piezometers PZ-1 and PZ-2 and the Aberjona River; and Staff Gauge SW-17) was determined to develop an estimate of the mass of organic and inorganic compounds that may be

discharging to the Aberjona River (Section 4.0, Risk Assessment). As specified in the GSIP Work Plan, the volume of ground-water discharge was calculated using Darcy's Law in the following manner, as described by Fetter, Jr. (1980):

$$Q = KIA$$

where:

Q	=	discharge (flow) rate $[L^3 \ T^{-1}]$
K	=	hydraulic conductivity $[L^2 \ T^{-1}]$
I	=	hydraulic gradient $[LL^{-1}]$
A	=	cross-sectional area $[L^2]$

Hydraulic conductivity (K) values were obtained from published sources and field data. According to Freeze and Cherry (1979), values for K for silt/clay materials to sand/gravel materials range eight orders of magnitude, from 10^{-2} gallons per day per square foot (gpd/ft^2) to $10^6 \ gpd/ft^2$. Because of the range in the size (grain) of the sediments encountered at Piezometer PZ-1 (i.e., clay with gravel, to sand with gravel and silt), the low and high values were not considered to be representative of the flow system, and the median value of 10^2 gpd/ft^2 was preliminarily chosen because it represented materials that were neither too coarse-grained nor too fine-grained (i.e., representative of a sand with silt). Furthermore, this value was considered representative based upon the following: 1) the lithology encountered in the borehole for Piezometer PZ-2, which consists of finer-grained sand with silt; 2) the variability of the aquifer matrix over short distances (e.g. the 25-ft distance between Piezometers PZ-1 and PZ-2; 3) the fact that the K had to representative of the distance over which the discharge calculation was made (i.e, approximately 270 ft); and 4) that, in the event that the aquifer matrix is finer-grained than anticipated and has a K less than $10^2 \ gpd/ft^2$, the calculated flux into the Aberjona River would be overestimated, and thus represent a conservative flux because the K for sand with silt is greater than that for finer-grained sediments such as clay with gravel. Additionally, a K of 280 gpd/ft^2 was calculated for Temporary Well TW-3S (Roux Associates, Inc., 1990b) from the pumping test conducted on October 31 through November 2, 1990. The sediments encountered in the borehole for Temporary Well TW-3S were fine to medium sand with silt. Because these materials, which were present at the location of Piezometers PZ-1, and predominant at the location of Piezometer PZ-2, are neither too coarse-grained nor too fine-grained, and the value of 280 gpd/ft^2 corroborates the preliminarily selected published value from Freeze and Cherry (1979), the value for K of 200 gpd/ft^2 was used in the flux analysis.

The hydraulic gradient (I) (i.e., the change in water-level elevations [Δh] divided by the change in distance in a given direction [Δl] [Fetter, Jr., 1980]) was calculated using Δh values for Piezometer PZ-1 and the Aberjona River. With a Δl of 25 ft (i.e., the distance between Piezometer PZ-1 and the Aberjona River), values for I were calculated for water-level elevations on April 10, 1990 and August 13, 1990. The Δh for April 10, 1990 was 0.55 ft (63.04 ft [Aberjona River] subtracted from 63.59 [Piezometer PZ-1]), and the Δh for August 13, 1990 was 0.66 ft (63.32 ft [Aberjona River] subtracted from 63.98 [Piezometer PZ-1]). Thus, the calculated I values range from a low of 0.022 ft/ft to a high of 0.026 ft/ft, (and average at 0.024 ft/ft).

The cross-sectional area of flow was calculated using the approximate depth of the Aberjona River of 1.5 feet multiplied by the approximate length (distance between Piezometers PZ-1 and PZ-2 to Staff Gauge SW-17) of 270 ft, (i.e., approximately 405 ft^2).

Based upon these data the range of discharge to the Aberjona River, within this 270 ft reach, is from 1,782 gallons per day (gpd) to 2,948 gpd, and averages 2,365 gpd. These low, high, and average values are equivalent to 6.6 gpd/linear ft of river, 10.9 gpd/linear ft of river, and 8.8 gpd/linear ft of river, respectively. All supporting calculations are provided in Appendix E. These discharge data were used in Section 4.0 to calculate the loading (i.e., the mass of organic and inorganic compounds discharging) to the Aberjona River from the ground water along this reach of the river.

3.2.2 Evaluation of Ground-Water Flow

Ground-water flow conditions were evaluated during the GSIP RI to assist in understanding the transport of inorganic and organic compounds through the unconsolidated aquifer (and into the streams) within the Study Area. The GSIP RI data collection efforts consisted of the measurement of water levels in all observation wells (GSIP RI, and PDI wells) over an initial minimum 6-month period to ensure that ground-water elevation data were developed during the range of fluctuations expected to be encountered during the study period. However, four additional synoptic rounds of water-level measurements were taken (one in December

1990, February 1991, April 1991, and May 1991), providing water-level data for all four seasons. In addition, water-level elevations were measured in adjacent surface-water drainages to ensure that ground-water/surface-water relationships were understood, and ground-water elevation (head)-and-flow conditions in the aquifer were representative of Study Area conditions.

Moreover, as required by the GSIP Work Plan, and where appropriate, the hydrogeologic data developed as part of the PDI were integrated into the GSIP program to ensure that program objectives were met (i.e., the collection of on-site and off-site hydrogeologic and water-quality data needed to characterize the flow system). The data developed as part of the PDI tasks, and incorporated into the evaluation of hydrogeological conditions within the Study Area, include Delineation of the Aquifer (Task GW-1/Subtask 1) (Roux Associates, Inc., 1990), and Hydrogeologic Characterization (Task GW-2/Subtask 1 and Subtask 2) (i.e., the constant-rate [pumping] test report (Roux Associates, Inc., 1990).

The pumping test was key to the understanding of ground-water flow, because the objectives of the pumping test were, as stated on page 72 of the PDI Work Plan (1989), to "quantify the hydraulic coefficients and characterize the boundary conditions of the flow system in order to design and operate a ground-water extraction system." The pumping test addressed these objectives by providing information on the quantification of the hydraulic coefficients of the flow system and on the characterization of the boundary conditions. (Roux Associates, Inc., 1990b).

Pumping test results indicated the following hydrogeologic conditions:

- the flow system becomes more prolific with depth, as evidenced by the K values which increase in depth in the aquifer;

- there is no change in directional transmissivity (T) and K, as values for these coefficients are similar for wells screened in similar depths of the water table, regardless of the direction from the pumping well (i.e., parallel, perpendicular, or oblique to the main buried valley walls);

- no-flow boundaries were not encountered, as indicated in the "S" shaped time versus drawdown plots for Temporary Well Clusters TW-1S/TW-1D through TW-4S/TW-4D, and Observation Well Cluster OW-19A/OW-19B (i.e., there were no additional

breaks [sudden and sustained increases] in the time versus drawdown plots for the above-mentioned temporary well clusters and observation well cluster, which indicates the cone of drawdown intercepting a no-flow boundary); and

- Hall's Brook is a recharge boundary to the aquifer under pumping conditions near the Brook, as evidenced by the water levels measured and plotted for Temporary Well TW-5, which showed that the drawdown in temporary well decreased and flattened as surface water through Hall's Brook stream bed infiltrated into the cone of drawdown created by Pumping Well PW-1 (Roux Associates, Inc., 1990b).

Thus, the flow system becomes more prolific with depth, no-flow boundaries were not evidenced, and no directional Ts and Ks were indicated within the area of the pumping test. Although Hall's Brook was determined to be a recharge boundary in the context of induced infiltration under the influence of a pumping stress, Hall's Brook is not a constant-head boundary because the Brook only penetrates a few feet (e.g. approximately 3 ft in the test area) into the total saturated thickness of the water-table aquifer (e.g. approximately 40 ft to 60 ft in the test area) (Plate 5).

3.2.2.1 Stratigraphy/Aquifer Characteristics

In order to develop a comprehensive understanding of ground-water flow conditions (conceptual flow model) a detailed framework of the lithology and geometry of the unconsolidated aquifer was developed. The extent of the following geologic materials encountered within the Study Area was mapped, as depicted in geologic Cross-Sections A-A' through E-E' (Plates 2 and 3) and in the surficial geologic map of the Study Area (Plate 4).

1. Crystalline Bedrock - Crystalline bedrock is present as outcrops on-site and can be encountered up to 108 ft below land surface in the southern portion of the Study Area. The variations in depth to bedrock are primarily a function of bedrock topography as the land surface is relatively flat.

This bedrock is comprised of igneous units which have undergone low grade metamorphism and several periods of deformation to form granodiorites and gabbros (Barosh, et al., 1977). During the installation of the observation wells during the PDI it was observed that the bedrock was fractured within the upper 3 ft and

became more competent with depth. However, the fractures were filled with either calcite (effectively sealing the fractures) or sand. The presence of filled fractures is consistent with the observation that the yields of the bedrock wells are generally less than 3 gallons per minute (gpm) (Stauffer, 1983).

2. Glacial Till - The glacial till (Qgm) overlies the bedrock along the valley walls and in the northern portion of the Study Area. The glacial till is encountered at depths up to 32 ft below land surface, and can be as much as 35 ft thick. The till is absent from the axis of the buried valley because the till was deposited as lodgement during Pleistocene time (Roux Associates, Inc., 1990a). The till consists of unsorted, boulders, cobbles, sand and gravel, silt and some clay. The till is dense (based upon observations made during drilling) and has a lower permeability than the overlying sand and gravel unit (Stauffer, 1983).

3. Sand and Gravel - The sand and gravel deposits (Qo2, Qo3, and Qo4) comprise the unconsolidated, (water-table) aquifer within the Study Area, and represent the greatest thickness of unconsolidated material within the buried valley. These deposits are encountered at depths ranging from land surface to 10 ft below land surface, and attain a maximum thickness of 115 ft within the southern portion of the Study Area (Plate 3). These deposits are glacial outwash, and consist of fine sand and coarse gravel with silt, silt lenses and some cobbles. The sand and gravel deposits are considered the most permeable based upon observations made during drilling and aquifer testing during the PDI.

4. Peat and Swamp Deposits - A thin, discontinuous unit of peat and swamp deposits (Qsd) are present in the northern, southern, and central areas of the Study Area. These deposits are encountered from land surface to 18 ft below land surface, and are as much as 14 ft thick (Plate 3). They consist of peat, organic silt, clay, and fine sand.

5. Fill - The fill materials are generally the shallowest deposits encountered. The fill is as much as 10 ft thick, and always occurs at land surface (Plate 3). The fill is a mixture of construction debris, fine sands, blasted bedrock fragments, and animal hides (on-site), and occurs above the water table.

Deposition of the till (Qgm) was over and around the remnants of glacial ice. As the next ice front advanced, outwash of clay with some interbedded sand and gravel was deposited in ponded water or marine embayments. This sequence (Qo2) is interpreted as lake deposits and associated stream deposits. The retreat of the ice sheet was the source of the glacial outwash deposits (Qo3) which are interpreted as predominantly braided stream deposits which deeply incise the earlier and broader valley. The final retreat of the glaciers coincided with the last outwash deposition (Qo4) which is thought to represent lake or pond sediments and alluvial fans. Late glacial streams eroded the valley where present streams, such as the Aberjona River, now flow. Since the last of the glacial ice melted some clay, silt, sand, gravel, and peat (Qsd) were deposited in lows occupied by streams, ponds and marshes (Roux Associates, Inc., 1990b).

The hydraulic conductivity (K) of the sand and gravel deposits (Qo2, Qo3, Qo4) was determined through the performance of a pumping test, as part of the PDI. This test was performed to develop data to support the design of the extraction well system specified in the Remedial Design Action Plan (RDAP) in the CD. The design of the step-drawdown (step test) and pumping test was outlined in the Work Plan developed by Roux Associates titled "Aquifer Test Work Plan, Task GW-2/Subtask 1, August 21, 1990" and the agreed to changes to that Work Plan (DeCillis, pers. comm., 1990). The results of the pumping test are summarized in the report titled "Pre-Design Investigation, Task GW-2, Hydrogeologic Characterization for the Extraction/Recharge System, Interim Final Report, Industri-Plex Site, Woburn, Massachusetts" (Roux Associates, Inc., 1990b).

The results of the pumping test are summarized in Table 3-4. These data indicate that the Qo3 unit, which is the thickest and most extensive lithologic unit present underlying the Study Area, has a K ranging from 1,392 gpd/ft^2 to 2,335 gpd/ft^2. Moreover, K increases with depth in the unconsolidated aquifer (e.g. 280 gpd/ft^2 for the upper portion of the water-table aquifer [Temporary Well TW-3S], to 530 gpd/ft^3 to 990 gpd/ft^2 for the middle portion of the water-

table aquifer [Temporary Well TW-1S/TW-2S and TW-4S, respectively], to 1,400 gpd/ft^2 to 2,600 gpd/ft^2 for the lower portion of the water-table aquifer Observation Well OW-19 and Temporary Well TW-4D, respectively] [(Roux Associates, Inc., 1990b]).

These calculated K values, especially those representative of the coarser (lower) portion of the water-table aquifer, corroborate published values developed south of the Study Area. Pumping tests were conducted in Wells G and H, which are located south of the pumping test Study Area. Hydraulic conductivities calculated from the Wells G and H pumping test ranged from 935 gpd/ft^2 to 2,618 gpd/ft^2 (Myette, *et al.*, 1987). These hydraulic conductivity values are similar to, or within the range of the K values obtained from the pumping test within the Study Area, and are therefore considered representative of similar deposits in the unconsolidated aquifer.

In addition to the hydraulic conductivity data developed as a result of the pumping test and from published data, qualitative measurements of hydraulic conductivity were obtained from Golder from slug tests run in 30 observation wells and temporary wells (Golder Associates, Inc., 1990). The results from the wells used in the pumping test indicate that the K values obtained from the slug tests for the wells tapping the shallower portion of the water-table aquifer (i.e., Temporary Wells TW-1S, TW-2S, TW-3S) are, for the most part, similar to the K values obtained from the pumping test for these respective temporary wells (Table 3-4). However, the K values obtained from the slug tests for the wells tapping the deeper portion of the water-table aquifer (i.e., Temporary Wells TW-1D, TW-2D, TW-3D), are different from the K values obtained from the pumping test. The K values from these slug tests (i.e., the deeper wells) are one order of magnitude to two orders of magnitude lower than the K values from the pumping test. Because the upper portion of the water-table aquifer has K values that are relatively low when compared to the K values of the lower portion of the water-table aquifer, the differences between slug test K values and pumping test K values for the lower portion of the water-table aquifer are as expected. Slug tests were designed for less prolific aquifers as a means of determining K under nonpumping test conditions; furthermore, slug tests measure K on a relatively small portion of the aquifer (relative to pumping tests)

(Bouwer, 1978). Thus, the more prolific the aquifer, the less likely that the slug test K values will be representative of the actual K. In addition, the greater the distance between a pumping well and the observation wells (of a pumping test), the more the K is an integrated value over those distances as compared to a K developed from a single well tapping a small, discrete zone of the aquifer.

3.2.2.2 Aquifer Geometry

The unconsolidated aquifer which underlies the Study Area is defined as those areas of the aquifer where the unconsolidated materials exceed approximately 10 ft in saturated thickness. However, this does not preclude portions of the unconsolidated deposits with saturated thickness less than, or approximately equal to, 10 ft from being saturated, and part of the flow system.

The limits of the unconfined aquifer (i.e., areas of the flow system where the saturated thickness is in excess of 10 ft) were determined from the borehole data obtained during the RI, GSIP RI, and PDI. The approximate areal extent of the saturated unconsolidated deposits greater than 10 ft thick are shown in Plate 6, and the areal extent of the aquifer is illustrated on Overlay 1. Water-table fluctuations within the on-site area of Piezometers PZ-1 and PZ-2 range from 65.24 ft to 62.00 ft for Piezometer PZ-1, and range from 64.88 ft to 62.29 ft for Piezometer PZ-2. The higher values of each range correspond to brief periods of high precipitation events when the Aberjona River is a losing stream. That is, ground-water elevations are increased as a result of recharge from the stream (as well as recharge from the precipitation event). However, as previously discussed, the Aberjona River is characteristic of a gaining stream (Plate 10). Regardless of the influent (losing stream) or effluent (gaining stream) nature of the Aberjona River, ground-water elevations can range from approximately 3.24 ft (Piezometer PZ-1) to about 2.59 ft (Piezometer PZ-2). As the water-table fluctuations within the Study Area vary, areas of the saturated unconsolidated (less than 10 ft in thickness) may become unsaturated during periods of low precipitation and infiltration. Consequently, only those areas that exceed 10 ft in saturated thickness are considered as part of the aquifer.

The buried valley, which controls the direction of flow of ground water in the unconsolidated aquifer, is part of the Fresh Pond Buried Valley. The Fresh Pond Buried Valley, which formed prior to the last period of glaciation of the region, has been traced from Wilmington to Boston,

Massachusetts and in general coincides with the axis of the Aberjona River (Chute, 1959). Based upon the data obtained during the drilling of soil borings and the installation of observation wells during the PDI the GSIP RI and geologic mapping, the buried valley is approximately 2 miles in width and over 100 ft in depth within the Study Area.

Glacial deposits form stratified drift sequences of unconsolidated sediments within the entire buried valley, and thin discontinuous till layers cover highlands in and around the valley. The presence of an inner gorge incised into the valley floor suggests at least one uplift of the land or the lowering of the sea level during the formation of the Fresh Pond Buried Valley. A tributary to the main axis of the buried valley underlies the area near (east of) Hall's Brook, and is represented as a thickening of the saturated unconsolidated deposits along the northwestern portion of the Site (Plate 6).

This main axis of the bedrock surface is illustrated on Plate 5 and Overlay 1. A detailed discussion pertaining to the buried valleys and their respective axes in conjunction with their influence on ground-water flow was provided in Section 3.2.

In order to depict the influence of the buried valley on the occurrence of the sand and gravel deposits which comprise the unconsolidated aquifer, a net sand isopach map was generated as part of the PDI (Roux Associates, Inc., 1990a). The map was developed from all of the RI, GSIP RI and PDI observation wells and soil borings borehole lithology logs, and represents the total thickness of sand within the unconsolidated aquifer. The net sand isopach shows a major depositional trough (represented by an area of thick net sand) which corresponds to the axis of the main buried valley. Well sorted, coarse grained sands were deposited through the central portion of the Study Area, and are coincident with the present course of the Aberjona River. The west side buried valley tributary consists of the on-site minor valley (as discussed below) and the off-site main valley which appears to be associated with Hall's Brook, and is represented by the thick net sand isopach in the northwest portion of the Study Area (Plate 7) (Roux Associates, Inc., 1990a). The axis of this combined minor and main buried valley, trends almost north to south, beginning as an on-site minor valley approximately coincident with a line projected between the East and West Hide Piles, through the area between Observation Wells OW-36 and OW-37, to and along the MBTA railroad tracks to Observation Well OW-14, towards Observation Wells OW-17 and OW-42. Within this area

(Observation Wells OW-17 and OW-42) is a confluence with a second minor valley (trending northeast to southwest, as previously discussed in Section 3.2), and the major valley continues to extend in a north to south direction, through the area between Observation Well Clusters OW-24A/OW-24B, and OW-19/OW-19A, and through Observation Well Clusters OW-33A/OW-33B, towards Observation Well Cluster OW-27A/OW-27B (Plate 5 and Overlay 1).

Data developed during the PDI and the GSIP RI indicate that the extent of the unconsolidated aquifer is defined by the limits of the remnant buried glacial valley incised into bedrock. Five depositional cycles have been recognized within the aquifer, and hydraulic characteristics vary within these sequences (Roux Associates, Inc., 1990a).

3.2.2.3 Saturated Extent of the Aquifer

As previously discussed, the areal extent of the aquifer is defined as the portions of the unconsolidated deposits that are greater than 10 ft in thickness (Plate 6). The saturated thickness of the unconsolidated aquifer is thin in areas where outcrops of the crystalline bedrock are present (northwest and southwest). Thinly saturated unconsolidated material and a bedrock outcrop are also present at the southeast portion of the Study Area.

Extensive areas of shallow bedrock (subcrop), where the unconsolidated deposits may be unsaturated depending on the season, are located on-site and oriented northeast-southwest. Two broad areas of shallow bedrock are separated by the main axis of the buried valley. These two areas of shallow bedrock and thinly saturated unconsolidated deposits extend from Observation Well OW-9 to Soil Boring ATB-12, and from Soil Boring ATB-18 to Observation Well OW-4 (Plate 6). Portions of these areas are likely not to be saturated throughout the entire year based upon the water-level elevation data collected as part of the GSIP. For example, the water-level elevation data collected at Observation Well OW-28 indicate ground water was present in the unconsolidated deposits near this well (i.e., saturated conditions) from April 1990 through May 1990, and in August 1990 and February 1991, but was essentially unsaturated or completely unsaturated from June 1990 through July 1990, and September 1990, December 1990, April 1991, and May 1991 (Table 3-5).

A similar observation was made at Observation Well OW-22 where water levels fluctuated approximately 3.69 ft during the period of measurement (Table 3-5). However, the unconsolidated deposits never became unsaturated. Although water levels and saturated thicknesses at Observation Well OW-22 fluctuated, the unconsolidated deposits remained saturated.

The presence of these thinly saturated areas on-site at Observation Well OW-28 will result in the movement of ground water through the unconsolidated aquifer in these areas on an intermittent (seasonal) basis, thus the total volume of ground water that will flow through this cross-sectional area will be relatively low when compared to the flow of ground water through the predominantly clean, well sorted sands and gravels which were deposited in the axes of the buried valleys.

3.2.2.4 Ground-Water Level Fluctuations

Ground-water elevations were initially measured in all observation wells from April 10, 1990 through September 26, 1990, and then measured again on December 7, 1990, February 26, 1991, April 17 to 19, 1991, and May 13, 1991, to determine the range of fluctuations of the water-table elevation on a seasonal basis (Table 3-5). (The expression "all observation wells" refers to the observation wells in Table 3-5 that have a water-level records from April 10, 1990 through May 13, 1991, specifically, Observation Wells OW-1A, OW-6, OW-7, OW-10 through OW-22, and OW-28.) These data indicate that over the period of measurement, ground-water elevations generally were at their lowest in July 1990, apparently in response to seasonal changes in precipitation and recharge. On-site ground-water levels varied from a high of approximately 4.285 ft (Observation Well OW-28, which goes dry) to a low of approximately 1.44 ft (Observation Well OW-11), and averaged about 2.37 ft (Table 3-5). Observation Wells OW-1A and OW-21, in the Study Area north of the Site, varied 3.15 ft and 1.62 ft, respectively, with an average fluctuation in ground-water levels of almost 2.39 ft (Table 3-5). Ground-water levels in the Study Area south of the Site varied from a high of about 1.86 ft (Observation Well OW-19A) to a low of about 1.38 ft (Observation Well OW-7), and averaged approximately 1.58 ft. (Table 3-5).

As expected, ground-water fluctuations on-site are greatest where the unconsolidated deposits are the thinnest and least transmissive because head responses to aquifer stresses (e.g. changing recharge) are most prominent in flow systems characterized by low permeability/low transmissivity deposits. For example, Observation Wells OW-28 and OW-22 have the two largest variations in heads over the period of measurement (Table 3-5) and are located in the thinnest deposits of saturated unconsolidated deposits (0.8 ft and 7.2 ft, respectively [Plate 6]). Conversely, Observation Well OW-11, which has the lowest variation in ground-water levels (Table 3-5), is situated in the thickest deposits of saturated unconsolidated deposits (34.3 ft [Plate 6]). Moreover, variations in heads over the period of measurement are greater on-site (with an average of 2.37 ft) than in the Study Area south of the Site (with an average of 1.58 ft). Again, this is to be expected because the flow system south of the Site is more prolific (i.e., characterized by more permeable, thicker, and more transmissive deposits). A representation of seasonal water-level fluctuations in on-site observation wells is illustrated in the continuous ground-water elevation measurements recorded in Piezometers PZ-1 and PZ-2 (Plate 10). The continuous ground-water elevation data indicate that in these two piezometers (PZ-1 and PZ-2), ground-water elevations fluctuated by as much as 3.24 ft and 2.59 ft, respectively. The magnitude of these fluctuations are of the order of those representative of the highest fluctuations in on-site observation wells. In summary, seasonal fluctuations of ground-water elevations in downgradient wells are lower than those measured on-site.

3.2.2.5 Ground-Water Flow Patterns

The ground-water elevation data for April 10, 1990 and for August 13, 1990 were contoured and are presented in Plates 8 and 9, respectively. Ground-water flow patterns are influenced by the geometry of the buried valleys and the extent and distribution of the well sorted (more permeable) sand and gravel deposits (Qo2, Qo3, and Qo4) (Plates 2, 3, 6, and 7). The influence of the geometry of the flow system with respect to ground-water flow is further evidenced on Figure 2 (i.e., the May 13, 1991 water-level map) where ground-water flow is directed towards, and channeled through, the two on-site minor buried valleys and the off-site main buried valley. The axes of these buried valleys are essentially coincident with the major portion of the flow field, i.e., the area of the flow field through which ground-water flow is predominately flowing.

The April 10, 1990 and August 13, 1990 ground-water elevation data represent ground-water elevations measured coincident with high flow (April 1990) and low flow (August 1990) surface-water sampling conditions. As stated above, water levels were also measured on December 7, 1990 as part of the PDI Phase 2 program, and on February 26, 1991, April 17 to 19, 1991, and May 13, 1991 to provide a synoptic round of ground-water and surface-water measurements. The May 13, 1991 data were contoured as shown in Figure 2. Although the water-table elevation was higher during the May 13, 1991 measurements than during the April 10, 1990 measurement round, which was in turn higher than the August 13, 1990 and December 7, 1990 measurement round, ground-water flow directions are similar.

The ground-water flow directions depicted during April 10, 1990, August 13, 1990, and May 13, 1991 (Plates 8 and 9, and Figure 2, respectively) indicate that ground-water flow is influenced by the distribution (occurrence) of the thickest section of sand (Plate 7), which is, in turn, controlled by the geometry of the buried valleys (Plate 5). Ground-water flow is from the two minor valleys in the northern portion of the Site to the south. The on-site buried valleys consist of two minor buried valleys, one whose axis trends northeast to southwest approximately coincident with a line extending from the vicinity of Recharge Test Borings RB-12 and RB-13, through Observation Well OW-16, towards Observation Wells OW-17 and OW-42 (Plate 5). Ground-water flow is controlled by the geometry of this buried valley, which contains thicker, more permeable sediments than the thin (i.e., less than 10-ft thick) section of unconsolidated deposits bounding the buried valley (Plate 7). Consequently ground-water flow is from the northeast to the southwest towards Hall's Brook Holding Area (Plates 8 and 9, and Figure 2). A second minor valley whose axis trends almost north to south, approximately coincident with a line projected between the East and West Hide Piles, through the area between Observation Wells OW-36 and OW-37, to and along the MBTA railroad tracks to Observation Wells OW-14, towards Observation Wells OW-17 and OW-42 (Plate 5). Again, ground-water flow is controlled by the geometry of this buried valley, which contains thicker, more highly permeable sediments than the thin (i.e., less than 10-ft thick) section of unconsolidated deposits bounding the buried valley (Plate 7). As a result, ground-water flow is towards Hall's Brook

and Hall's Brook Holding Area (Plates 8 and 9, and Figure 2). At the confluence of these two minor valleys (i.e., the area around Observation Wells OW-17 and OW-42), the major valley continues to extend in a north to south direction, through the area between Observation Well Clusters OW-24A/OW-24B and OW-19/OW-19A, through Observation Well clusters OW-33A and OW-33B, towards Observation Well clusters OW-27A and OW-27B (Plate 5 and Overlay 1).

As illustrated by the equipotential lines on Plates 8 and 9, and on Figure 2, ground water flows from the vicinity of Observation Well OW-11 towards Observation Well Cluster OW-30A/OW-30B. In the vicinity of Observation Well Cluster OW-30A/OW-30B, shallow ground water discharges into Hall's Brook Holding Area, while deeper ground-water flow is beneath Hall's Brook Holding Area, into and along the main buried valley east of Hall's Brook. This ground-water flow pattern in conceptualized in Figures 3 and 4, and will be discussed in greater detail in Section 3.2.2.8.

Because the horizontal component of ground-water flow is controlled by the buried valleys, shallow ground water flows towards, and into, the streams (i.e., the streams are discharge boundaries to the shallow flow system). With the absence of a substantial vertical hydraulic gradient, and thus the absence for the potential for vertical flow (either predominantly upward of downward based upon a comparison of heads in well clusters [Table 3-6]), ground-water flow at depth is also horizontal, (as will be discussed in subsequent sections). Based upon the water-level data from the well clusters, the gradients are low (thousandths to tens of thousandths ft/ft) and they fluctuate from upward to downward to no gradient (i.e, horizontal flow). Ground-water flow and ground-water/surface-water relationships fall into two apparent patterns. The first pattern is the flow of shallow ground water towards, and into, the streams (e.g. Hall's Brook Holding Area, (Figures 3 and 4). The second pattern, which is based upon the concept of horizontal flow through the aquifer, is that ground water flows down the two minor, on-site buried valleys, converges in the area around Observation Wells OW-17 and OW-42, and follows the axis of the main buried valley (i.e., the buried valley that extends south from the area around Observation Wells OW-17 and OW-42). Thus, with converging flow towards the main buried valley, ground water is re-oriented at depth (i.e., below the shallow flow system) to follow the axis of the valley (Figure 4).

This pattern is conceptualized on Figure 4 which shows the orientation of the flow lines depicting ground water at depth flowing along (i.e., parallel with) the main buried valley. Thus, it is unlikely that ground water at depth (i.e., below the shallow flow system) from the east side of Hall's Brook Holding Area can flow beneath the Holding Area and to the west side of the Holding Area because ground water would have to flow from a more transmissive area (thicker portion of the aquifer) to a less transmissive area (thinner portion of the aquifer) (Plate 6), which contradicts a fundamental principle of ground-water that follow the "easiest" (i.e., more prolific) flow path (Freeze and Cherry, 1979). Furthermore, it is more likely that ground water at depth flows from the west side of Hall's Brook Holding Area to the east side of Hall's Brook Holding Area based upon the following information:

- the limits of the aquifer (i.e, the aquifer boundary) are only on the order of 500 ft (or less) west of Hall's Brook Holding Area (Overlay 1);
- ground-water flow would be from the limits of the aquifer (and a thin saturated zone) towards the thick, more prolific buried valley (and axis) to the east of Hall's Brook Holding Area (Plates 8 and 9, Figures 2, 3, and 4);
- ground water flows under the prevailing hydraulic gradient (i.e., from areas of higher head to areas of lower head) which converges on, and is re-oriented with, the axis of the buried valleys (Plates 8 and 9, Figures 2, 3, and 4); and
- ground water will not flow from east to west underneath Hall's Brook Holding Area, towards the limit of the aquifer where ground water is entering the flow system (Plates 8 and 9, Figures 2, 3, and 4).

In summary, ground water is flowing from the northern portion of the Study Area towards the southwest and then to the south (Plates 8 and 9, and Figure 2). Shallow ground water flows towards the streams and discharges into the surface-water bodies (Figures 2, 3, and 4). Ground water at depth (i.e., below the shallow flow system) flows towards, and along, the axes of the two minor buried valleys and then along the axis of the main buried valley. Ground water at depth is not likely to flow from east to west underneath Hall's Brook Holding Area, but can apparently flow from west to east beneath Hall's Brook Holding Area (Figures 2, 3, and 4).

In addition, the water-table beneath the East and West Hide Piles appears to be mounded, that is, affected by local ground-water highs (i.e., areas of high head). This is based upon data obtained by Golder during Task S-2 (Stability of Hide Piles) of the PDI (Golder Associates, Inc., 1990). As illustrated in Figure 2, an equipotential line (e.g. the 70-ft isocontour) encircles the West Hide Pile orienting ground-water flow predominantly to the east (and Lower South Pond), with components of ground-water flow to the northeast and south (also towards Lower South Pond). Thus, ground-water flow appears to be toward Lower South Pond, with eventual discharge of shallow ground water into the pond. Similarly, an equal equipotential line (e.g. the 70-ft isocontour on Figure 2) wraps around the East Hide Pile orienting ground-water flow to the west (and Lower Pond), and south. This mounding is likely due to the elevated topography of the Hide Piles. Elevated topographic surfaces can be areas where ground water accumulates and highs occur as recharge from precipitation infiltrates the topographic high, allows for the storage of water as it takes longer for the water to percolate down to the water table, and eventually allows for the build-up of head under the topographic high (i.e., the thicker sequence of materials capable of storing water).

3.2.2.6 Horizontal Hydraulic Gradients and Flow Rates

Horizontal hydraulic gradients range from approximately 0.008 ft/ft (between Observation Wells OW-22 and OW-17 [$\Delta h = 21.56$ ft and $\Delta l = 2,400$ ft]) on-site to 0.004 ft/ft (between Observation Wells OW-13 and OW-19 [$\Delta h = 9.14$ ft and $\Delta l = 2,300$ ft]) downgradient of the Site during April 10, 1990. Similar hydraulic gradients of 0.008 ft/ft to 0.004 ft/ft (between Observation Wells OW-22 and OW-17, and Observation Wells OW-13 and OW-19, respectively) were measured on August 13, 1990. The changes in horizontal gradients observed reflect the changes in geologic materials present within the Study Area. The steeper gradients observed on-site reflect the greater percentage of finer-grained (less permeable) material and a thinner saturated zone than is present off-site in the main axis of the buried valley. Conversely, the hydraulic gradient for the more permeable, coarser-grained sediments will be lower, as less energy is needed to drive ground-water flow.

The range of ground-water flow rates (seepage velocities) was calculated based upon the Site-specific hydraulic conductivity data developed during the pumping test and slug tests (performed during the PDI), and the measured hydraulic gradients. The seepage velocity was calculated using the following formula provided in Fetter (1980):

$$v = K/n_e \, dh/dl$$

where:
v	=	seepage velocity [LT^{-1}]
n$_e$	=	effective porosity [dimensionless]
K	=	hydraulic conductivity [LT^{-1}]
dh/dl	=	horizontal hydraulic gradient (I)$_h$ [LL^{-1}]

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In order to estimate the range in horizontal ground-water (seepage) velocities along a flow path from the West and East Hide Piles area to Hall's Brook Holding Area, the following data were substituted into the equation from Fetter (1980):

- an estimated range for n$_e$ of 25 percent (0.25) to 30 percent (0.30) for mixed sand and gravel deposits (Fetter, Jr., 1980);

- an average calculated K of 280 gpd/ft^2 (Temporary Well TW-3S, which is similar to the average K [212 gpd/ft^2] determined from slug tests on Observation Well OW-17 [Golder Associates, Inc., 1991a]) and of 530 gpd/ft^2 (Temporary Wells TW-1S and TW-2S) from the pumping test (Roux Associates, Inc., 1990b); and

- an I$_h$ of 0.009 ft/ft (from a flow line extending from Observation Well OW-22 to Observation Well OW-17 [$\Delta l = 2,400$ ft and $\Delta h = 21.56$ ft]) (Plate 8).

The resultant range of ground-water flow rates is approximately from 1.12 ft/day to 2.55 ft/day. All supporting calculations are provided in Appendix E.

The ground-water velocity calculations were coupled with the equation that relates distance to velocity (rate) and time (i.e., Distance [D] = Rate [R] multiplied by Time [t]). Using the range in ground-water velocities (rates) of 1.12 ft/day and 2.55 ft/day, and the distance of 2,400 ft between Observation Wells OW-22 and OW-17, the time for ground water to flow from Observation Well OW-22 to Observation Well OW-17 ranges from 2.6 years to 5.9 years.

3.2.2.7 Vertical Hydraulic Gradients and Flow Rates

An evaluation of the vertical component of ground-water flow within the unconsolidated aquifer was performed using water-level data obtained in observation well clusters installed as part of the PDI program and the observation wells installed as part of the RI. These data are summarized in Table 3-6.

Water-level data indicate that vertical gradients within the unconsolidated deposits range from 0.040 ft/ft downward (at Observation Well Cluster OW-27A/OW-27B [$\Delta l = 53.56$ ft and $\Delta h = 2.14$ ft]) to 0.026 ft/ft upward (at Observation Well Cluster OW-24A/OW-24B [$\Delta l = 34.98$ ft and $\Delta h = 0.92$ ft]). During the period of measurement, the highest downward vertical gradient is 0.007 ft/ft at Observation Well Cluster OW-25A/OW-25B ($\Delta l = 17.05$ ft and $\Delta h = 0.12$ ft), and ranges as low as 0.002 ft/ft in Observation Well Clusters OW-24A/OW-24B, OW-25A/OW-25B, and OW-33A/OW-33B, excluding Observation Well Clusters OW-27A/OW-27B (all dates), and OW-18/OW-18A and OW-30A/OW-30B (on June 20, 1990). These data were not included in the vertical flow rate calculations because they are an order of magnitude higher than the overall data base (Table 3-6).

The highest upward vertical hydraulic gradient is 0.005 ft/ft measured at Observation Well Clusters OW-26A/OW-26B ($\Delta l = 19.01$ and $\Delta h = 0.10$) and OW-19/OW-19A ($\Delta l = 31.26$ ft and $\Delta h = 0.16$ ft) excluding the vertical gradient measured at Observation Well Cluster OW-24A/OW-24B of 0.026 ($\Delta l = 34.89$ and $\Delta h = 0.92$) on December 7, 1990. Moreover, five of the eight observation well clusters (i.e., OW-18/OW-18A, OW-24A/OW-24B, OW-25A/OW-25B, OW-30A/OW-30B, and OW-33A/OW-33B) and had no vertical hydraulic gradient on at least one occasion during the period of measurement. Therefore, the upward or downward gradients do not reflect the potential for significant upward or downward vertical flow in the unconsolidated aquifer, excluding those measured at Observation Well Cluster OW-27A/OW-27B.

The downward vertical gradient measured at Observation Well Cluster OW-27A/OW-27B reflects a contrast in hydraulic conductivities between the two lithologic zones screened by the well cluster. Observation Well OW-27A is screened in fine-grained to medium-grained sand in the upper portion of the aquifer, while Observation Well OW-27B is screened in silt with traces of sand and clay in the lower portion of the aquifer. The hydraulic conductivity for the sand zone is higher than that of the silt zone (Freeze and Cherry, 1979), which results in the differences in heads evidenced between the two wells. Regardless, Observation Well Cluster OW-27A/OW-27B is located at the most downgradient location within the Study Area adjacent to Mishawum Road. Therefore, this downward vertical gradient is not considered representative of the remainder of the Study Area.

The vertical ground-water flow rates were calculated using the vertical hydraulic conductivities (from the aquifer test results; Roux Associates, Inc., 1990b), measured vertical gradients, and estimated effective porosities. The vertical flow rate was calculated using the following formula provided in Fetter, Jr. (1980):

$$v = K/n_e \, dh/dl$$

where: v = seepage velocity $[LT^{-1}]$
n_e = effective porosity [dimensionless]
K = hydraulic conductivity $[LT^{-1}]$
dh/dl = vertical hydraulic gradient (I_v) $[LL^{-1}]$

In order to estimate the range in downward vertical seepage velocities from the water table to the base of the unconsolidated aquifer the following data were substituted into the equation from Fetter, Jr. (1980):

- an average estimated n_e of 28 percent (0.28) for mixed sand and gravel deposits from Fetter, Jr. (1980).

- calculated range of K_z (vertical hydraulic conductivity) of 2 gpd/ft^2 to 57 gpd/ft^2 (Temporary Wells TW-4S and TW-1D, TW-2D, and TW-3D, respectively) from the pumping test (Roux Associates, Inc., 1990b).

- a range of I_v (vertical gradients) from 0.002 ft/ft to 0.007 ft/ft, respectively from water levels in Observation Wells OW-33A, OW-33B, OW-25A and OW-25B (Δl = 39.68 ft and Δh = 0.08 ft, and Δl = 16.6 ft and Δh = 0.12 ft, respectively), measured on August 13, 1990 (Table 3-6).

The resultant range of potential downward ground-water flow rates is from approximately 0.002 ft/day to 0.191 ft/day. However, because the I_v fluctuates and no sustained downward I_v is present throughout the Study Area, these values are conservative, at best, and not representative of general aquifer conditions.

Because the I_v data for the observation well clusters indicate that there is no well cluster (with the exception of Observation Well Cluster OW-27A/OW-27B) with a sustained downward I_v (Table 3-6), a calculated range in downward travel times from the water-table surface to the bottom of the aquifer is not reasonable.

The potential for the vertical flow between the unconsolidated deposits and the underlying bedrock can be estimated for the Study Area. Of the three bedrock observation wells (OW-1, OW-4, and OW-9) present in the area, the potential for vertical flow was evaluated for two (i.e., Observation Wells OW-1 and OW-9) because these wells are either part of a cluster well (OW-1/OW-1A) or are close enough so as to be considered as part of a "cluster well" (OW-9 with OW-14, which is approximately 360 ft to the west of OW-9).

Based upon the record of ground-water elevation data (Table 3-5), the heads in Observation Well OW-1 (bedrock formation observation well) have consistently been lower (approximately 0.22 ft to 1.5 ft) than heads in Observation Well OW-1A (unconsolidated formation observation well). Conversely, based upon the same record of water-elevation measurements, the heads in Observation Well 9 (bedrock formation observation well) have, with the exception of heads measured on August 13, 1990 which essentially show equal values, been higher (approximately 0.5 ft to 1.0 ft) than the heads in Observation Well OW-14 (unconsolidated formation observation well) (Table 3-6 and Figure 6). Thus, based upon the existing data base, a potential for vertical migration of ground water downward (from the unconsolidated formation into the bedrock formation) only exists north of the Site (Observation Wells OW-1 and OW-1A). Because Observation Well Cluster OW-1/OW-1A is located in the northern portion of the Study Area, and is also apparently located near the portion of the aquifer where the unconsolidated deposits are thin (relative to the buried valleys) (Figure 2 and Overlay 1, respectively), this area may be a recharge area to the flow system. If this is the case, then the potential for ground-water flow from the unconsolidated deposits into bedrock (i.e. recharging the unconsolidated and bedrock flow systems) exists. However, based upon available data, a potential also exists for upward vertical migration of ground water upward (from the bedrock formation into the unconsolidated formation). This flow pattern would result in recharge to the unconsolidated deposits in this area of the Site.

3.2.2.8 Conceptual Ground-Water Flow Model

Conceptual ground-water flow models for the Site and the Study Area (Figures 3 and 4, respectively) were developed to assist in understanding ground-water flow conditions, ground-water/surface-water relationships, and the transport of inorganic and organic compounds in

the ground water. These conceptual models were developed from the hydrogeological data obtained during the PDI, GSIP, and RI programs. The conceptual models will also be used to assist in the development of the numerical flow model during the RD program.

A representation of the conceptual flow model in the vertical plane is presented in Figure 4, while a representation of the conceptual flow model in the horizontal plane is displayed in Figure 4. Ground-water flow in the unconsolidated aquifer is from recharge areas in the higher portions of the Site and Study Area to the Aberjona River and Hall's Brook. In general, the shallow ground water (i.e., ground water at approximately the same depth below the water-table surface as the depth of the bottom of the stream [i.e., the streambed]) discharges to the surface waters on-site and within the Study Area, while deeper ground-water flows in response to the aquifer geometry, that is, to and parallel with the two minor on-site buried valleys and to and parallel with the main buried valley south of the Site (Figures 3 and 4). Flow is from the surface waters to the ground-water system only during periods of high surface-water flow (storm events), as previously discussed and as illustrated in Plate 10.

The cross-sectional, conceptual, hydrogeologic model developed for the Site is also based upon head data from Observation Wells OW-9 and OW-14, which indicate a potential for upward flow of ground water from the crystalline bedrock into the overlying unconsolidated aquifer. Published information suggests that leakage from the till and crystalline bedrock into the overlying unconsolidated deposits may occur as indicated by vertical and horizontal gradients near the sand and gravel/till-bedrock boundaries within the area south of the Site (Myette, et al., 1987). The results of the study performed by Myette, et al. support the interpretation that the potential for ground-water flow is from the crystalline bedrock upward into the unconsolidated aquifer within the GSIP Study Area. The only exception (as discussed above) may be in the area to the north of the Site where recharge may be occurring, and there is an apparent potential for ground-water flow from the unconsolidated deposits to the bedrock.

The potential for ground-water flow, and the transport of inorganic and organic compounds, through the crystalline bedrock underlying the Site is considered unlikely based upon the following:

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- published information from Myette, *et al.* (1987) which states that wells completed in bedrock yield only a few gallons per minute, (i.e., the bedrock is characteristic of a low transmissivity unit with a low potential for flow);

- field data that indicates the potential for flow from the bedrock to the overlying unconsolidated deposits; and

- the nature of the fracturing within the bedrock.

As stated above, water-level data from Observation Wells OW-9 and OW-14 indicates the potential for ground-water flow up from the bedrock into the unconsolidated water table.

With respect to the nature of the fracturing within the bedrock, the upper 3 ft to 5 ft of the crystalline bedrock was cored during the installation of the monitoring wells and the drilling of the soil borings during the PDI and the GSIP. (Photographs of the bedrock cores are provided in Appendix B along with the geologic logs.) An evaluation of these bedrock cores indicates that the cores are fractured but the cores are predominately filled with calcite and sand. The presence of fracture filling minerals and sand will further reduce the overall transmissivity of the crystalline bedrock.

In conclusion, an evaluation of the water-level data and bedrock cores indicates that the potential for flow through crystalline bedrock is probably limited, especially in comparison to flow through the higher transmissive unconsolidated deposits.

3.2.3 Nature and Extent of Migration

An evaluation of the nature and extent of inorganic and organic compounds migrating in ground water was performed and is discussed in the following sections (3.2.3.1 and 3.2.3.2). This evaluation was based upon all usable (qualitative and quantitative) water quality data developed as part of the GSIP and PDI programs. The PDI data were developed from the Phase 1 and Phase 2 programs designed to define the extent of hazardous substances in ground water within the Study Area.

The GSIP sampling was performed from March 15 through 22, 1990. Additional, resampling was performed on April 25, 1990 because some critical data collected from March 15 through March 22, 1990 were validated as unusable. The Phase 1 PDI sampling was performed from

June 4 through June 6, 1990 according to the requirements of the PDI Work Plan (Golder Associates, Inc., 1989). PDI Phase 2 sampling was performed from October 15 to October 18, 1990 and November 7, 1990 to further define the extent of benzene and toluene "hot spots". A summary of these data are provided in Appendix C. The GSIP, and Phase 1 and Phase 2 PDI analytical data are presented in Plates 11 and 12. The concentrations of benzene/toluene, dissolved arsenic, and dissolved chromium detected during the GSIP RI and PDI were contoured as shown in Figures 7, 8 and 9.

The analytical program for the GSIP was performed by Enseco-ERCO Laboratory (ERCO) Cambridge, Massachusetts. The analytical data for the ground-water samples are provided in Appendix C. Radian Corporation of Austin, Texas performed the metal speciation, organo-tin, organo-mercury and the Fe^{+2} analyses. The Radian data are also provided in Appendix C.

The GSIP data were validated according to USEPA Region 1 guidelines presented in "Functional Guidelines for Evaluating Organic Analyses, November 1989" and "Functional Guidelines for Evaluating Inorganic Analyses, November 1989" and the data validation procedures presented in the GSIP Work Plan. The data validation documentation is provided in Appendix D.

The GSIP and PDI ground-water quality data were entered into a computer data base (dBase III+) to facilitate retrieval and evaluation of the data. The entire data base was examined to determine the nature and extent of the inorganic and organic compounds in the ground water.

The types of constituents present were identified for upgradient Site boundary, on-site, and off-site (downgradient) observation wells to determine what impact(s) may be attributed to the Site, if any.

The upgradient Site boundary observation wells are OW-1A and OW-21 (Plate 1).

The on-site observation wells are:

OW-10	OW-31
OW-11	OW-32
OW-12	OW-36
OW-13	OW-37
OW-14	OW-38
OW-15	OW-39
OW-16	OW-40
OW-22	OW-41
OW-23	OW-42
OW-28	

The off-site observation wells are:

OW-6	OW-25B
OW-7	OW-26A
OW-17	OW-26B
OW-18	OW-27A
OW-18A	OW-27B
OW-19	OW-29
OW-19A	OW-30A
OW-20	OW-30B
OW-24A	OW-33A
OW-24B	OW-33B
OW-25A	

3.2.3.1 Nature of the Constituents Detected

Organic compounds detected in the upgradient Site boundary, on-site, and off-site (downgradient) observation wells are summarized in Tables 3-8 and 3-9, and listed on Plate 11.

The data developed during the GSIP RI and the PDI programs identified five base/neutral compounds bis(2-ethylhexyl)phthalate, diethylphthalate, acenaphthalene, 1,3 dichlorobenzene, and N-nitrosodiphenylamine (Tables 3-8 and 3-9). Data developed during the GSIP and PDI programs indicate that phenol, 2-methylphenol and 4-methylphenol were detected in the observation wells listed below.

	OW-16 μg/L	OW-17A μg/L	OW-17 μg/L	OW-12 μg/L	OW-21 μg/L
phenol	130	430	6	3	190
2-methylphenol	ND	ND	ND	ND	9
4-methylphenol	3,400	ND	ND	ND	DRAFT

No PCB or pesticide compounds were detected in the ground water during the GSIP RI and PDI programs.

In addition, no ethylmercury, monomethyl tin, dimethyl tin, or trimethyl tin were detected during the GSIP RI sampling. Although the analytical method for dimethyl-mercury could not be developed, the absence of total mercury in ground water suggests that it is unlikely that it is present in the ground water.

A comparison of the types of organic compounds detected in upgradient Site boundary, on-site, and off-site areas indicates that the types of VOCs detected upgradient Site boundary and on-site differ from VOCs detected off-site (downgradient) (Tables 3-8 and 3-9, and Plate 11). Although halogenated VOCs were detected downgradient of the Site, these compounds were not detected on-site or upgradient.

Benzene was detected on-site at a maximum concentration of 48,000 micrograms per Liter (μg/L) in Observation Well OW-31, and off-site at a maximum concentration of 2,000 μg/L at Observation Well OW-17. However, based upon the direction of ground-water flow (Plates 8 and 9, and Figure 2) and the distribution of benzene in the remainder of the on-site observation wells (Plate 11), benzene is not migrating from Observation Well OW-31 to Observation Well OW-17. Regardless, it is apparent that benzene from on-site has affected ground water downgradient and off-site, adjacent to the Hall's Brook Holding Area (i.e., Observation Well OW-17), (Plate 11 and Figure 7). Toluene has been detected on-site at a concentration of 32,000 μg/L at Observation Well OW-16 (Plate 11). It is apparent that toluene from on-site (i.e., Observation Well OW-12) has affected ground water downgradient and off-site, adjacent to the Hall's Brook Holding Area (Plate 11 and Figure 7).

With respect to the remaining five VOCs (chloroform, xylenes, methylene chloride, acetone, ethylbenzene) found on-site (Table 3-8), there is no connection between the on-site and off-site constituents. The highest concentration of chloroform on-site is 6 μg/L at Observation Well OW-22 (Plate 11), which is only 1 μg/L above the Contract Required Quantitation Limit (CRQL) of 5 μg/L, while the highest concentration of chloroform off-site is 4 μg/L at Observation Well OW-30B (Plate 11), which is less than the CRQL, and, thus reported as qualitative (Appendix C). Likewise, the highest concentration for xylenes on-site is 1 μg/L at Observation Well OW-32 (Plate 11), which is considered qualitative (i.e., less than the CRQL of 5 μg/L). Although methylene chloride was detected on-site at concentrations of 22 μg/L at Observation Well OW-22, and was detected off-site at a maximum concentrations of 23 μg/L at Observation Well OW-27A, methylene chloride is not attributed to the Site, because: 1) Observation Wells OW-27A and OW-27B are on the west side of Hall's Brook, out of the flow path from Observation Well OW-23; 2) methylene chloride is not detected in any of the observation wells downgradient of Observation Well OW-23 (i.e., OW-24A, OW-24B, OW-33A, OW-33B, OW-7, and OW-20); and 3) methylene chloride is a common laboratory contaminant and may have been introduced during water quality analyses.

The highest concentrations of acetone and ethylbenzene on-site are 6 μg/L in Observation Well OW-4 (bedrock well only) and 1 μg/L in Observation Well OW-32, respectively. These concentrations are below the CRQL of 10 μg/L and 5 μg/L, respectively, and are therefore reported as qualitative (Appendix C). Moreover, neither acetone nor ethylbenzene are found in any off-site observation wells. Thus, of the seven on-site constituents listed in Table 3-8, only off-site detections of benzene and toluene are attributable to on-site "hot spots."

The types of inorganic compounds detected during the GSIP RI for upgradient, on-site, and off-site (downgradient) areas are summarized in Appendix C and posted on Plate 12.

3.2.3.2 Extent of the Constituents Detected
The GSIP and PDI data were compared to determine the types of compounds that would be mapped for purposes of defining the extent of migration of any of these compounds in the ground water. All of the organic compounds detected during the GSIP and PDI Phase 1 and Phase 2 sampling events were mapped since relatively few compounds were detected (Plate 11). As stated above, only benzene and toluene are present (i.e., quantitative values)

in adjacent wells to delineate a plume or "hot spot" (Plate 11 and Figure 7). Again, as presented above, these mapped data were compared to ground-water flow data to determine their approximate extent in the ground water and to identify potential source areas.

Among the inorganic compounds, the dissolved concentrations of arsenic, chromium, lead, and zinc detected during the GSIP RI and PDI Phase 1 and Phase 2 sampling events are posted on Plate 12. The plumes of arsenic and chromium are contoured as shown on Figures 8 and 9, respectively. Additional discussions of the evaluation of the extent of the above-mentioned four metals in ground water are provided in the results of the Metals Mobility Study (Section 3.5).

The evaluation of the nature and extent of metals in ground water is based upon the analytical data from the dissolved (filtered) samples. The dissolved samples are considered most representative of ground-water quality conditions because the total (unfiltered) samples can contain solids (greater than 0.45 microns in size) that are not transported within the formation. These solids can be introduced into the sample from the formation, by passing through the gravel pack and well screen. In contrast, the dissolved sample constituents provide data along with colloidal material transported within the formation. Colloidal material is less than 0.45 microns in size and current research indicates that inorganic and organic compounds can be transported as colloidal size materials within an aquifer.

Upgradient Site Boundary

The evaluation of ground-water quality upgradient Site boundary and migrating onto the Site consisted of a review of the ground-water quality data from Observation Wells OW-1, OW-1A and OW-21, and a consideration of any potential source areas upgradient of the Site. A summary of ground-water quality in Observation Wells OW-1, OW-1A and OW-21 is provided in Appendix C.

As previously discussed, only a few organic compounds were detected in the upgradient observation wells (Plate 11). Of the organic compounds detected in Observation Well OW-1 (i.e., chlorobenzene [25 μg/L], chloroethane [3 μg/L], chloromethane [1 μg/L], and benzyl alcohol [4 μg/L]), only chlorobenzene is detected at a concentration greater than its CRQL of 5 μg/L. Chloroethane, chloromethane, and benzyl alcohol are all detected at concentrations

that are less than their respective CRQL values of 10 μg/L per compound and are therefore considered qualitative values (Appendix C). Chloroform was detected at a concentration of 2 μg/L and toluene at a concentration of 6 μg/L in Observation Well OW-21, and bis(2-ethlyhexyl)phthalate was detected at a concentration of 4 μg/L in Observation Well OW-1A. Chloroform and bis(2-ethylhexyl)phthalate are reported at concentrations below the CRQL of 5 μg/L and 10 μg/L, respectively, and are therefore considered qualitative values (Appendix C). Although toluene is reported at a concentration of 6 μg/L, it is only 1 μg/L above the CRQL, and its detection is considered doubtful (i.e., the use of this value as quantitative is questionable). Thus, if these compounds are present, they reflect the presence of industrial activities immediately north of the Site.

Of the four dissolved metals (i.e., arsenic, chromium, lead, and zinc) posted on Plate 12, only zinc is detected in Observation Wells OW-1 (25.4 μg/L) and OW-1A (8.2 μg/L), and zinc and chromium are detected in Observation Well OW-21 (15.7 μg/L and 25.1 μg/L, and 9.8 μg/L, respectively). In all cases, the concentrations of zinc are below (8.2 μg/L and 15.7 μg/L), or slightly above (approximately 25 μg/L) the CRDL of 20 μg/L, and are reported as qualitative or not detected (Appendix C). The chromium concentration of 9.8 μg/L (Observation Well OW-21) is below the CRDL of 10 μg/L, and is also reported as qualitative (Appendix C). Thus, there appears to be no quantitatively reported concentrations of these four dissolved metals that are flowing on-site immediately north and northwest of Observation Wells OW-1, OW-1A, and OW-21.

<u>On-Site</u>
Benzene, in excess of the CRQL concentration of 5 μg/L, was detected at the following locations near the East and West Hide Piles (Observation Wells OW-31 (48,000 μg/L) and OW-32 (41 μg/L), respectively), and at Observation Wells OW-17 (2,000 μg/L), OW-12 (300 μg/L) and OW-41 (27 μg/L) (Plate 11). The highest concentrations of benzene were detected in Observation Well OW-31 (48,000 μg/L) located at the base of the West Hide Pile and at Observation Well OW-17 (2,000 μg/L) located on the northeastern side of the of the Hall's Brook Holding Area.

Toluene, in excess of the CRQL concentration of 5 μg/L, was detected in seven observation wells (OW-9, OW-12, OW-16, OW-22, OW-39, OW-41, and OW-42) (Plate 11) Concentrations detected were as high as 32,000 μg/L in Observation Well OW-16 and as low as 9 μg/L in Observation Well OW-41.

Although toluene was detected in Observation Wells OW-17, OW-20, OW-23, OW-24B, OW-27B, OW-30B,and OW-33B, the concentrations ranged from a low of 1 μg/L to a high of 3 μg/L, and, consequently, were below the CRQL of 5 μg/L. Therefore, these concentrations are considered qualitative (Appendix C).

Based upon the ground-water quality data developed during the GSIP and the PDI programs, the benzene/toluene "hot spots" are located on-site along the eastern flank of the West Hide Pile (Observation Well OW-31) and from Observation Well OW-16 to Observation Well OW-17 located approximately 250 feet south of the Site. The approximate extent of detected concentrations of benzene/toluene in ground water is shown in Figure 7. The extent is represented by the concentrations of benzene/toluene that exceed 10 μg/L.

The extent of the benzene/toluene detected during the GSIP RI and the PDI programs, coupled with the data from the installation and sampling of 61 temporary monitoring wells by Stauffer during 1984, suggests that the potential source areas of the benzene/toluene are:

1. the east flank of the East Central Hide Pile;

2. upgradient of the Observation Well OW-16, north of the trailer compound;

3. on the southeast flank of the East Central Hide Pile; and

4. in the developed area south of Atlantic avenue.

The last three discrete potential source areas listed above are represented by the plume of benzene/toluene extending from Observation Well OW-16 to OW-17 as depicted on Figure 7. This plume is migrating with ground-water flow towards the Hall's Brook Holding Area.

The benzene "hot spot" located near the West Hide Pile is limited in extent to the eastern flank of the West Hide Pile. This "hot spot" has not migrated off-site or downgradient towards Observation Wells OW-37 and OW-38 (Figure 7) because of the local ground-water high (i.e., the equipotential line [e.g. 70-ft isocontour on Figure 3]) which appears to wrap around the West Hide Pile orienting ground-water flow to the northeast and south, towards Lower South Pond). If benzene was present throughout the West Hide Pile, then it would likely have been detected in Observation Wells OW-36 and OW-37 (as the dissolved arsenic and chromium were [Figures 8 and 9, respectively]), which are in the downgradient flow path from the West Hide Pile.

The extent of arsenic detected in ground water during the GSIP RI and PDI programs is shown in Figure 8. Arsenic plumes were detected downgradient of: 1) the West Hide Pile; 2) the East-Central Hide Pile; and 3) the South Hide Pile (Figure 8).

The arsenic plume downgradient of the West Hide Pile is defined by the dissolved concentrations of arsenic at Observation Wells OW-36 (256 μg/L), OW-37 (343 μg/L), and OW-38 (120 μg/L). This discrete plume of arsenic has migrated downgradient of the West Hide Pile with ground-water flow (Plates 8 and 9, and Figure 2) towards, but not as far as, Observation Wells OW-10 and OW-14. Based upon the absence of arsenic in Observation Well OW-10 and the qualitative dissolved arsenic concentrations detected in Observation Well OW-14 (7.5 μg/L and 4.1), the arsenic plume downgradient of the West Hide Pile has only migrated to an area between Observation Wells OW-38 and OW-14 (Figure 8).

The arsenic plume downgradient of the East-Central Hide Pile follows the orientation of ground-water flow (Plates 8 and 9, and Figure 2) as it is channeled down the minor, on-site buried valley (Plate 5). This arsenic plume is defined by dissolved arsenic concentrations in Observation Wells OW-16 (28,600 μg/L), OW-39 (29.3 μg/L), OW-13 (43.5 μg/L), and OW-41 (34.4 μg/L) (Plate 12 and Figure 8).

The arsenic plume downgradient of the South Hide Pile also follows the orientation of ground-water flow (Plates 8 and 9, and Figure 2) as it is channeled down the minor, on-site buried valley (Plate 5). This plume is defined by dissolved arsenic concentrations in Observation Wells OW-12 (556 μg/L), OW-42 (500 μg/L), and OW-17 (164 μg/L) (Plate 12 and Figure 8).

The arsenic detected in ground-water at Observation Well OW-32 (23 μg/L) at the western flank of the East Hide Pile, is attributed to the hide pile located immediately upgradient.

Arsenic was also detected at Observation Well OW-11, where the concentration was reported to range from a low of 98.4 μg/L to a high of 198 μg/L (Plate 12). Based upon the direction of ground-water flow, and, in particular, the ground-water high in the vicinity of the West Hide Pile, Observation Well OW-11 is not within the flow path from the West Hide Pile (Plates 8 and 9, and Figure 2). Thus, it appears that dissolved arsenic is due to localized concentrations of arsenic in soils adjacent to the wells.

Two plumes of dissolved chromium in ground water were identified downgradient of: 1) the West Hide Pile; and 2) the East-Central Hide Pile. These chromium plumes although located at the same locations as the arsenic plumes, have not migrated as far downgradient as the arsenic.

The chromium plume located downgradient of the West Hide Pile (Plate 12 and Figure 9) is defined by the concentrations detected in Observation Wells OW-36 (121μg/L), OW-37 (449 μg/L), and OW-38 (15.6 μg/L). This plume of chromium has migrated with ground-water flow from the West Hide Pile towards Observation Well OW-38 (Plates 8 and 9, and Figure 2).

A second dissolved chromium plume was detected downgradient of the East-Central Hide Pile (Figure 9). This follows the orientation of ground-water flow (Plates 8 and 9, and Figure 2) as it is channeled down the minor, on-site buried valley (Plate 5) and is defined by the concentrations in Observation Well OW-16 (252 μg/L), OW-39 (23.5 μg/L) and OW-41 (23.4 μg/L) (Plate 12 and Figure 9).

The dissolved chromium detected at Observation Well OW-9 (455 μg/L) may be attributed to potential problems with well construction. The age of this bedrock well and the presence of chromium in the soils at the chromium lagoons, suggests that dissolved chromium in the ground water (unconsolidated deposits) is migrating along the well into the underlying bedrock.

Other detections of dissolved chromium on-site have occurred in Observation Wells OW-31 (37.1 μg/L) and OW-32 (51.1 μg/L), (Plate 12). These detections may be attributable to the West Hide Pile and the East Hide Pile, respectively.

The presence of discrete dissolved arsenic and chromium plumes located downgradient of the hide piles is due to the presence of geochemical conditions present in the hide piles and, metal containing soils. A geochemical paradigm was developed as part of the Metals Mobility Study (Section 3.5) which explains the mobility of arsenic and chromium in the ground water downgradient of the hide piles.

In summary, ground-water flow patterns and the orientation of the plumes agree with the geologic data, developed during the GSIP and PDI programs, that the west and east branches of the minor, on-site buried valleys merge into a single, more deeply incised main buried valley near Observation Wells OW-17 and OW-42, and the Hall's Brook Holding Area. The discharge of the benzene/toluene, and arsenic-impacted ground water into the Hall's Brook Holding Area apparently prevents its migration further to the south along the axis of the main buried valley.

Downgradient

The benzene/toluene plume and the arsenic plume downgradient of the East-Central and South Hide Piles is migrating off-site towards Observation Well OW-17 and the Hall's Brook Holding Area (Figures 7 and 8, respectively).

The arsenic plume identified downgradient of the South and East-Central Hide Piles may extend to Observation Wells OW-19A (35.4 μg/L), and OW-30A and OW-30B (47 μg/L and 16.4 μg/L, respectively). Although ground-water flow data suggests that underflow from the east side of the Hall's Brook Holding Area to the west (and Observation Well Cluster OW-30A/OW-30B) is unlikely, and the presence of arsenic in Observation Well Cluster OW-30A/OW-30B may be attributed to lateral dispersion of the plume within the buried valley aquifer. The presence of arsenic in Observation Well OW-19A may also be attributable to

the arsenic plume from the hide pile, as Observation Well OW-19 is located within the axis of the buried valley downgradient of the hide piles. Since the ground-water extraction system planned for the Site, as required by the CD (Golder Associates, Inc., 1991), will be located upgradient of these wells along the axis of the buried valley, it is reasonable to assume that the concentration of arsenic at these wells would be expected to decrease over time as arsenic-impacted ground water is intercepted by these extraction wells.

As previously discussed, chlorinated VOCs that are not attributed to the Site (since these compounds were not detected on-site) were detected in an area along Hall's Brook and at Observation Well OW-26B (Plate 11). Thus, the presence of chlorinated compounds and the extent of these compounds indicate that they are associated with potential source areas south of the Site (off-site), and not attributable to the Industri-Plex Site.

3.2.3.3 Discussion of Woburn Landfill

The Woburn Sanitary Landfill, is located to the northwest of the Site near Observation Wells OW-1, OW-1A, and OW-11. The landfill consists of approximately 54 acres and is bordered by New Boston Street to the east (Figure 4). The location of the landfill with respect to the Site was considered in evaluating the quality of the ground water migrating onto the Site. Several investigations have been conducted at the Woburn Landfill. A preliminary landfill assessment was performed by Ecology and Environment, and is summarized in the report titled "Preliminary Site Assessment of Woburn Sanitary Landfill, August 1980."

A more comprehensive evaluation of hydrogeological conditions was performed by D.E. Reed (1982) and summarized in the report titled "Hydrogeological Investigation-Woburn Sanitary Landfill, Woburn Massachusetts."

The results of the 1988 sampling by the Maguire Group, Inc. indicated the presence of benzene (12 μg/L), chlorobenzene (25 μg/L), ethylbenzene (19 μg/L), and toluene (7 μg/L) in Monitoring Well MG-1 located downgradient of the landfill. In addition, semi-volatile compounds, (naphthalene [47 μg/L] and 2-methylnaphthlene [25 μg/L]) were detected in this well.

Additionally, the results of the inorganic analyses performed during the 1989 sampling by the Maguire Group indicates that (of the metals selected for mapping as part of the GSIP) arsenic and chromium were not detected in the monitoring wells sampled (MG-1 and MG-2C [downgradient], and MG-5 [upgradient]). However, lead was detected at 80 μg/L (Monitoring Well MG-1), 160 μg/L (Monitoring Well MG-2C), and 110 μg/L (Monitoring Well MG-5). In addition, zinc was detected at 1,320,000 μg/L in Monitoring Well MG-2C and at 530 μg/L in Monitoring Well MG-5.

Based upon the 1989 Maguire Group, Inc. report, "groundwater flows in a southeasterly direction" (Maguire, 1989, page 12, conclusion 1, line 1). The Maguire Group also concludes that "groundwater is intercepted by the brooks along the southern perimeter of the landfill" (page 13, conclusion 2) and "there is little, if any, flow of groundwater under the brook, as evidenced by the steep groundwater surface on either side of the south perimeter brook" (page 13, conclusion 3). Therefore, based upon the data obtained during the GSIP RI and the conclusions developed by the Maguire Group, Inc. (1989), it is reasonable to conclude that the streams located along the perimeter of the landfill likely flow into the Unnamed Tributary and the New Boston Street Drainway, and that if ground water is flowing beneath the streams (underflow) it is flowing towards and along the axis of the on-site, minor buried valley.

Upgradient observation wells (OW-1, OW-1A, and OW-21) have concentrations of dissolved arsenic, chromium, lead, and zinc as posted on Plate 12. The concentrations of dissolved zinc are 8.2 μg/L (Observation Well OW-1), 25.4 μg/L (Observation Well OW-1A), and 15.7 μg/L to 25.1 μg/L (Observation Well OW-21), which apparently indicate that ground-water flow from the landfill is more south than west. This direction of flow seems to be confirmed by the concentrations of zinc along the western portion of the Site, which indicate that zinc may be migrating from the area of the Woburn Landfill onto the western portion of the Site near Observation Well OW-11. As shown in Plate 12, the concentrations of dissolved zinc at Observation Wells OW-10, OW-11, OW-14, and OW-18 (7,250 μg/L, 1,600 μg/L, 1,610 μg/L, and 8,990 μg/L, respectively) are the highest detected within the Study Area and are located downgradient of the Woburn Landfill.

In an attempt to better understand the relationship between the location of the landfill plume and the Site, chloride was chosen as a tracer in ground water. Chloride is a conservative ion that is used extensively to define ground-water plumes emanating from sanitary landfills (Kimmel and Braids, 1980). The levels of chloride detected in ground water were compared for several wells which surround the landfill. Of the seven landfill wells sampled by the Maguire Group in September 1988, two were located upgradient of the landfill (Monitoring Wells MG-4 and MG-5), four were located downgradient of the landfill (Monitoring Wells MG-1, MG-2A, MG-2B, and MG-2C), and one was located cross-gradient of the landfill (Monitoring Well MG-3) (Maguire Group, Inc., 1989). The September 1988 data from RI Analytical Laboratories, Inc. indicate that ground water upgradient and cross-gradient of the landfill has a much lower chloride content (15.5 milligrams per Liter [mg/L] to 22 mg/L, respectively) than the ground water immediately downgradient of the landfill (275 mg/L to 480 mg/L, respectively) (Maguire Group, Inc., 1989). Conductivity readings (1,550 micromhos per centimeter [μmhos/cm] to 4,210 μmhos/cm) (Maguire Group, Inc., 1989), and sodium levels (730 mg/L [Monitoring Well MW-4]) (H.W. Moore & Associates, Inc., 1983) in the downgradient ground-water samples also indicate the presence of a plume extending from the landfill.

The ground-water samples collected during the GSIP RI were analyzed for chloride content. Two observation wells installed as part of the GSIP RI, are located directly east of the landfill, adjacent to New Boston Street. The ground water from these two observation wells, OW-1A and OW-11, contained chloride and sodium concentrations similar to the Woburn Landfill background concentrations (i.e., less than 5 mg/L chloride and 11.6 mg/L sodium in Observation OW-1A, and 19.7 mg/L chloride and 14.6 mg/L sodium in Observation Well OW-11). These results further suggest that the landfill plume has not migrated directly east, but follows the area's ground-water flow toward the south-southeast, and eventually into, and directed by, the buried valleys (Plates 8 and 9, and Figures 2 and 4).

Based upon the 1990 analytical results from Observation Wells OW-10, OW-14, and OW-18, ground water downgradient (south-southeast) of the landfill contains sodium and chloride constituents in similar background concentrations to those evidenced at the landfill (less than 100 mg/L. Observation Well OW-18 contained a higher chloride concentration than Observation Wells OW-10 and OW-14, which are located between the landfill and Observation

Well OW-18. This implies that the chloride found in Observation Well OW-18 may be attributable to another source, or may travel through more prolific saturated sediments. Based upon the chloride (19.7 mg/L, 15.7 mg/L, and 98.4 mg/L, respectively) and sodium levels (14.6 mg/L [14,600 μg/L], 12.7 mg/L, and 63.1 mg/L, respectively), the ground water in Observation Well OW-11 may not have been impacted by the plume from the landfill. It may also be likely that the landfill plume has not impacted Observation Wells OW-14 and OW-18.

3.3 Surface-Water Investigation

The objective of the surface-water migration task was to evaluate the extent and character of metals and organic compounds in the surface-water drainage system on-site and in the surrounding areas of the drainage basin both upstream and downstream of the Site (Roux Associates, 1989). To accomplish this objective, the surface-water hydrology of the Study Area was characterized as a basis for assessing migration of inorganic and organic compounds in surface water. Surface-water hydrology was evaluated to provide a more comprehensive understanding of the inter-relationship between the ground water and surface water of the Study Area.

3.3.1 Hydrology

The surface-water hydrology of the Study Area was characterized through the performance of several field tasks, evaluation of published information available for the surface-water drainage and performance of the following field investigations:

- identification and mapping of surface-water drainages within the Mystic River drainage basin;

- inventory of existing discharges through field inspection and aerial photograph interpretation; and

- the measurement of flow rates and volumes at 17 locations within the Study Area (Tables 3-10 and 4-37).

Concurrent with the measurement of ground-water levels within the Study Area, surface-water levels were measured at SW-1, SW-3, SW-7 and SW-14 to provide data regarding the relationship between surface water and ground water. The surface-water elevation data are

provided in Table 3-11. In addition, continuous water level measurements in the Aberjona
River were obtained adjacent to piezometers PZ-1 and PZ-2 to assist in evaluating surface
water/ground-water relationships. This evaluation was discussed in detail in Section 3.2.

Surface-water flow rates and volumes were measured at 17 observation locations (Table 3-12)
during high flow (April 1990) and low flow (August 1990) conditions to determine the seasonal
fluctuations in flow rates. In addition, flow data were collected at SW-5, SW-10, SW-12, SW-14
and SW-17 on four additional occasions (for a total of six measurement rounds) to supplement
the data base.

3.3.1.1 Discharge Areas

Drainage areas within the Study Area were characterized through a review of published
information field mapping, and a review of the following aerial photographs.

- LIU Aerial Survey   Watertown, CT   1"=100'   November 22, 1989 Black and White
- Flight Survey and Mapping Newbury, MA   1"=300'   January 5, 1990   Color
- Flight Survey and Mapping Newbury, MA   1"=300'   March 27, 1990   Color

The Study Area (Figure 1) is located within the Mystic River Basin and is drained by the
Aberjona River, Hall's Brook and several smaller drainages (Plate 1). The Aberjona River
north of Route 128 drains approximately 5.54 square miles and Hall's Brook drains
approximately 1.51 square miles north of New Boston Street (USGS, 1984).

The Aberjona River originates northeast of the Site and flows in a southerly direction through
the Study Area. The floodplain of the Aberjona River consists mostly of industrially developed
areas (Woburn Flood Insurance Study, 1980). The Northern Branch of the Aberjona River
enters the northeast section of the Site and flows toward the southwest. This branch moves
to the south at SW-4, where it is fed by a culvert which drains the Lower South Pond (West
Branch). This pond, located between the East and West Hide Piles, drains the northwest
section of the Site. Within the Study Area, the Aberjona is fed by a culvert which drains
the Lower South Pond, between the West and East Hide Piles and the northeast portion of
the Site. At SW-4 the West Branch of the Aberjona converges with the Northern Branch
of the Aberjona. The Northern Branch drains the northeast portion of the Site.

Further south, the Aberjona River is fed by discharge from Phillips Pond (South Branch of the Aberjona). The Aberjona River continues flowing south and then westward towards Mishawum Road, where it converges with Hall's Brook.

The Atlantic Avenue Drainway drains the area adjacent to, and north of, the South Hide Pile and the Chromium Lagoons (Plate 1).

Hall's Brook enters the Study Area from the west near wells OW-18/18A and drains into the Hall's Brook Holding Area (Plate 1). In addition, the New Boston Street Drainway and an Unnamed Tributary join Hall's Brook before it flows into Hall's Brook Holding Area. Based upon the results of the investigation performed by Maguire Group, Inc., 1989, "groundwater is intercepted by the brooks along the southern perimeter of the landfill" (page 13, conclusion 2). These brooks likely discharge into the New Boston Drainway and Unnamed Tributary located west of the Industri-Plex Site.

The Hall's Brook Holding Area and Phillips Pond were constructed for flood control purposes following the filling of Lake Mishawum (Wetlands Management Specialists 1986). The construction of these flood control basins was approved by the US Army Corps of Engineers and the Massachusetts Department of Natural Resources. The Hall's Brook Holding Area and Phillips Pond are successful in reducing flood flow in the Aberjona River (Woburn Flood Insurance Study, 1980).

3.3.1.2 Inventory of Discharges

During mapping of the surface-water drainages, discharges to the surface waters were identified to assist with the evaluation of surface-water quality data (Plate 14). The locations of these discharges were considered during the evaluation of surface-water and stream-sediment chemical data. These discharges to the surface-water drainages were identified through field mapping.

3.3.1.3 Flow Rates

As required by the CD, and as specified in the GSIP RI Work Plan, surface-water flow rates were measured at the 17 observation stations during high flow and low flow conditions to characterize flow conditions and to evaluate the relationship between surface water and ground

water. Measurements were made on April 19, 1990 and July 31 through August 3, 1990. These flow measurements and discharge volumes are provided in Table 3-12 and depicted in Plates 15 and 16, respectively.

Flow data recorded during high flow conditions (April 19, 1990) totaled 8.87 cubic feet per second (cfs). Flow into the Study Area is 8.08 cfs at SW-10, 0.17 cfs at SW-2, and 0.62 cfs at SW-4. Flow out of the Study Area is approximately 9.86 cfs as measured at SW-14, located downstream of the confluence of the Aberjona River and the Hall's Brook Holding Area.

During low flow conditions (July 31 through August 3, 1990), flow into the Study Area was approximately 2.12 cfs (combined flow at SW-1, SW-4 and SW-10) and flow out of the Study Area was approximately 4.27 cfs at SW-14. The decrease in the flow rate out of the Study Area during low flow conditions, when compared to high flow conditions, primarily reflects a decrease in surface-water runoff and a relative increase in the contribution of ground water (base flow) to the surface-water drainages.

Based upon an average of the August 21, and September 26, 1990 surface-water flow data (Table 3-12), the relative contribution of each of the surface-water drainages to the flow at SW-14 was estimated. Based upon these estimates, Hall's Brook (upstream of SW-10) contributes approximately 43 percent of the total flow measured at SW-14, the Hall's Brook Holding Area contributes approximately 27 percent of the flow, and the Aberjona River contributes approximately 29 percent to the flow.

Flow rates within the Aberjona River range from less than 0.002 cfs at SW-2 (August 3, 1990) to 2.21 cfs at SW-12 (August 21, 1990). In contrast, Hall's Brook ranges from 0.60 cfs (July 17, 1990) to 8.08 cfs (April 19, 1990) at SW-10. The flow from the Hall's Brook Holding Area at SW-13 ranges from 2.18 cfs (July 31, 1990) to 5.49 cfs (April 19, 1990). It is apparent from these flow data that Hall's Brook contributes the greatest volume of flow at SW-14 in comparison to other surface drainages within the Study Area.

3.3.1.4 Sediment Transport

During the measurement of stream flow rates at high flow conditions (April 19, 1990) suspended sediment and stream sediment samples were collected to provide an estimate of

the total volume (suspended and bedload fractions) of sediments entering (SW-3 and SW-7) and leaving the Study Area (SW-14). It was anticipated that bedload would be calculated, (to permit the total sediment load to be estimated) using stream discharge and stream-sediment grain size distribution data according to the method developed by Colby and Hembree (1955). However, the Colby and Hembree method assumes that stream discharge will be greater than 2 feet per second; and that the minimum water depth will be greater than 1.0 ft. Since water depths were less than 0.89 feet (at SW-14 on April 19, 1990) and velocities less than 1.80 ft/sec (at SW-10 on April 19, 1990) (Appendix B) total sediment transport (suspended and bedload fractions) could not be calculated.

Data descriptive of bedload transport in surface-water drainages of the Study Area were not available. However, published information indicates that bedload comprises approximately 5 to 50 percent of the total sediment load of a stream (Dunne and Leopold, 1978). Assuming approximately 50 percent of the total sediment load transported in the surface-water drainages is bedload, and using the total suspended sediment load of 207 lbs/day to less than 265 lbs/day at SW-14 (Table 3-15), an estimate of 414 lbs/day to less than 530 lbs/day for the total sediment load can be developed (total sediment load minus suspended load equals the bedload).

Although the total sediment load could not be calculated using the Colby and Hembree method, a measurement of the volume of sediment being transported as suspended load into and out of the Study Area was obtained for both high flow (April 19, 1990) and low flow (July 31 through August 3, 1990) conditions.

Surface-water samples collected during low flow conditions were analyzed for total suspended solids in addition to concentrations of inorganic and organic compounds (Table 3-15).

These estimates indicate that from 207 lbs/day to less than 265 lbs/day of suspended sediments are flowing from the Study Area at SW-14. Approximately 0 lbs/day to 0.45 lbs/day at SW-3 (I-93 Drainway) and 10.94 lbs/day to 19.41 lbs/day at SW-7 (New Boston Street Drainway) of suspended sediments are entering the Study Area from the north (upstream).

An estimate of the suspended sediment transport from Hall's Brook can be calculated based upon the suspended solids concentration measured at the time of low flow sampling at SW-10. Suspended sediment concentrations were not measured at SW-10 during high flow conditions (in accordance with the GSIP RI Work Plan). Using the measured discharge of 2.11 cfs and a total suspended solids concentration of less than 5.0 mg/L, a discharge of less than 56.89 lbs/day was calculated (Table 3-16).

The concentrations of total suspended solids measured during low flow conditions provides a qualitative assessment of the relative importance of each surface-water drainage in transporting suspended solids within the Study Area (Table 3-16). These data indicate that the highest volume of suspended solids are entering the Study Area from the west through Hall's Brook and the New Boston Street Drainway. The low flow suspended solids concentrations also indicate that the concentrations of suspended solids measured at SW-14 (207 lbs/day) are primarily attributable to the Hall's Brook Holding Area and not the Aberjona River as indicated by the concentration of suspended solids recorded at SW-12 along the Aberjona River (less than 16.17 lbs/day). The data also suggest that the Hall's Brook Holding Area north of SW-13 traps suspended sediments entering from Hall's Brook and the New Boston Street Drainway. It is also likely that area south of SW-13 and the Hall's Brook Holding Area, which is a wetland (approximately one half mile in length), would be another depositional area. Based on the flow data recorded during this investigation, the Atlantic Avenue Drainway (SW-16) does not appear to be a conduit for the transport of suspended solids since it did not have a measurable discharge during the high flow sampling (<0.01 cfs) and was dry during the low flow sampling period.

3.3.2 Nature and Extent of Migration

An evaluation of the nature and extent of inorganic and organic compounds migrating in the surface water was performed and is discussed in the following sections (3.3.2.1 and 3.3.2.2). This evaluation of the nature and extent of migration of inorganic and organic compounds was based upon all usable water quality data developed during the August 1990 GSIP RI surface-water sampling. Surface-water quality data were not developed during the PDI.

The analytical program for the GSIP RI was performed by Enseco-ERCO Laboratory (ERCO) Cambridge, Massachusetts. Radian Corporation, Austin, Texas performed the metal speciation, organo-tin, organo-mercury and Fe^{+2} analyses. These data are provided in Appendix C. Field measurements are provided in Table 3-13.

The GSIP RI sampling of surface waters was performed during low flow conditions from July 31 through August 3, 1990 at the locations shown on Plate 1 and described in Table 3-10. Analytical data for the volatile organic compounds are presented in Plate 17 and the concentrations for arsenic, chromium, and lead, are depicted in Plate 18.

Samples were collected for total (unfiltered) and dissolved (filtered) analyses. Only total samples were collected for VOCs and metal speciation analyses.

As part of the surface-water investigation, trunk sewer lines passing through the Study Area were sampled at two locations per sewer. This sampling was performed from April 24, 1990 to April 26, 1990 at the locations shown on Plate 13. All analyses were performed by ERCO for Target Compound List (TCL) and Target Analyte List Metals (TAL) compounds.

The surface-water and sewer discharge samples were validated according to USEPA Region 1 guidelines presented in "Functional Guidelines for Evaluating Organic Analyses, November 1989" and "Functional Guidelines for Evaluating Inorganic Analyses, November 1989" and the data validation procedures outlined in the GSIP RI Work Plan. The data validation documentation is provided in Appendix D.

As with the ground-water data, the surface-water data were entered into a computer data base (dBase III+) to facilitate the retrieval and evaluation of the data. The entire data base was examined to determine the nature and extent of inorganic and organic compounds in the surface water.

Constituents present at upstream Site boundary, on-site, and downstream surface-water observation locations (SW-1 through SW-17) for both Hall's Brook and the Aberjona River were identified to determine what impacts may be attributed to the Site, if any.

The upstream Site boundary surface-water observation stations are:

Hall's Brook	Aberjona River
SW-6	SW-1
	SW-3

The on-site surface-water monitoring stations are:

Hall's Brook	Aberjona River
SW-7	SW-2
SW-15	SW-4
SW-10	SW-8
SW-16	SW-17

The downstream surface-water observation stations are:

Hall's Brook	Aberjona River	Both
SW-9	SW-5	SW-14
SW-11	SW-12	
SW-13		

Surface-water stations were grouped to facilitate discussion of trends in the analytical data. For purposes of this discussion, upstream Site boundary stations are the sample locations furthest upstream. In some cases they are within the Site boundary but upstream of on-site influences such as hide piles. On-site stations are those on-site and influenced by on-site conditions. Downstream stations are downstream of the Site.

3.3.2.1 Trunk Sewer Line Sampling

The locations of sewer lines within the Study Area were determined through a review of easement maps supplied by the Town of Woburn. Based upon an evaluation of this information, two trunk sewer lines that pass through the Study Area were identified namely

the City of Woburn and the Town of Reading trunk lines. The City of Woburn trunk sewer line was sampled at SR-3 (upgradient) and SR-4 (downgradient). The Town of Reading trunk sewer line was sampled at SR-2 (west) and SR-1 (east) (Plate 1). Analytical results for the sewer sampling is provided in Appendix C.

The sewer lines were sampled from April 24 to April 26, 1990. No sediment was present in any of the trunk sewer lines during the sampling period and as a result no sediment samples were collected.

Data for the City of Woburn trunk sewers indicate that several VOCs and semi-VOCs were detected in the upgradient sampling location (SR-3). Of the organic compounds detected, acetone and toluene were detected in the highest concentrations (480 μg/L and 290 μg/L, respectively). Semi-VOCs were detected in concentrations not exceeding 34 μg/L (bis(2-ethylhexyl)phthalate). Arsenic was detected in the upgradient sample at 5.2 μg/L (total).

The downgradient concentrations of these constituents are similar to those detected in the upgradient samples. Acetone was detected in SR-4 at 110 μg/L and the semi-VOCs were detected in lower concentrations (maximum concentration of semi-VOC was 33 μg/L for 4-methylphenol [dissolved sample]). The concentration of arsenic in SR-4 was 2.0 μg/L (total).

These data indicate that the concentrations of organic and inorganic compounds are lower in the downgradient sample (SR-4) than in the upgradient sample (SR-3) for the City of Woburn trunk sewer line.

Data for the Town of Reading sewer line (SR-1 and SR-2) indicate that fewer organic compounds were detected than in the City of Woburn trunk sewer line, and that those present occurred in lower concentrations. Metal concentrations were of comparable magnitude between the two samples collected at the east (SR-1) and west (SR-2) boundaries of the Site.

In summary, results of analyses performed on water samples from the trunk sewer lines indicate that concentrations of organic and inorganic compounds are not higher in the downgradient samples (SR-2, SR-4) than the upgradient samples (SR-1, SR-3).

3.3.2.2 Surface-Water Analyses

Analytical results from the August 1990 sampling of surface water at the 17 monitoring stations within the Study Area were used to determine the types of constituents present and their extent. Dry conditions were encountered at two of the surface-water sampling locations, SW-3 and SW-16, which prevented collection of samples at these locations. Data were compared to the ground-water flow and quality data to determine if these constituents are discharging to the surface-water drainages within the Study Area.

3.3.2.2.1 Nature of the Constituents Detected

The types of organic compounds detected are listed in Tables 3-17 and 3-18. Only three metals (beryllium, nickel and zinc) were detected in both the Aberjona and Hall's Brook surface-water stations. Neither beryllium nor nickel were detected in surface-water samples collected during the GSIP RI.

No PCB or pesticide compounds were detected in surface water during the GSIP RI sampling. In addition, no ethyl-mercury, monomethyl tin, dimethyl tin, and trimethyl tin was detected in the surface-water samples during the GSIP RI (Radian, 1990). As previously discussed, no analytical method could be developed for dimethyl mercury.

The organic compounds detected in the upstream, on-site, and downstream locations for Aberjona River Stations and Hall's Brook stations are summarized in Tables 3-17 and 3-18, respectively and also on Plate 17.

A review of the organic compounds detected in surface-water samples indicates that the acetone concentration of 20 μg/L at SW-2 was the highest organic compound concentration detected. In addition, many of the compounds are considered common lab contaminants (i.e., methylene chloride, acetone, toluene and common phthalate esters) and may not accurately represent surface-water quality. While these data were validated as usable, many compounds are detected at concentrations near the detection limits. For example, di-n-butylphthalate was detected at SW-1 at 3 μg/L in a dissolved sample. Absence of this compound in the total sample, plus the low detected concentration, make the result questionable.

Comparison of the total and dissolved sample results indicates that the same types of semi-volatile organic compounds, at similar concentrations, were detected in both total and dissolved samples (Appendix C). Only total VOC samples were collected in accordance with the GSIP RI Work Plan.

Both dissolved and total TAL metals were analyzed at surface-water sampling locations. In addition, analyses for tin were performed as specified in the GSIP RI Work Plan. Metals generally detected in surface-water samples include arsenic, barium, calcium, iron, lead, magnesium, manganese, potassium, sodium, and zinc. Generally, the same metals were seen in stations on both the Aberjona River and Hall's Brook drainages.

A comparison of the dissolved and total metals samples from each location indicates that the same metals were seen in both the dissolved and total analyses at similar concentration ranges, with the exceptions of chromium and lead which were detected only in the total metal samples.

3.3.2.2.2 Extent of the Constituents Detected

As specified in the GSIP RI Work Plan, the data developed during the GSIP RI were compared to those developed during the RI to assist in determining the extent of organic and inorganic compounds in the ground water. Specifically, the GSIP RI and RI data were compared to determine the types of compounds that would be mapped for purposes of defining the extent of migration in the surface-water drainages. All of the VOCs detected in the surface water were mapped since relatively few compounds were detected (Plate 17). All organic compounds detected are listed in Tables 3-17 and 3-18.

Sampling of surface waters was performed during low flow conditions (July 31 through August 3, 1990) in accordance with the GSIP RI Work Plan. The collection of surface-water samples during low flow conditions minimized dilution of the samples from precipitation and runoff events. Therefore, the analytical data obtained likely represent worst case conditions than if the samples were collected during high flow conditions.

For the inorganic compounds, the concentrations of arsenic, chromium, and lead were mapped. The concentrations of these metals detected in surface water are depicted in Plate 18. These metals were selected for mapping based upon their frequency of detection and concentration. A discussion of organic (i.e., benzene, toluene) and inorganic compounds (i.e., arsenic, chromium and lead) detected in the upstream, on-site, and downstream surface-water sampling locations on the Aberjona River flow follows.

The extent of the constituents detected was evaluated within each surface-water body in the Study Area (e.g. Aberjona River). In this manner, surface-water quality at upstream Site boundary, on-site, and downstream surface-water stations at the Site could be more accurately evaluated.

Surface water stations on the east side of the Site are located on drainage areas that flow into, or are in, the Aberjona River. These stations include the upstream Site boundary (SW-1, SW-3), on-site (SW-2, SW-4, SW-8, SW-17), and downstream (SW-5, SW-12, SW-14) groups and are discussed in these groups.

Aberjona River - Upstream Site Boundary/Organics - Evaluation of the organic surface-water quality flowing onto the Site, for the Aberjona River flow system, included the review of data from one upstream station, SW-1, which was located at the north end of the Lower South Pond. SW-3, located at the northeast corner of the Site is also considered an upstream station, but was dry during the surface-water sampling. Only di-n-butylphthalate was detected in the dissolved sample collected from SW-1 at 3.0 μg/L. As mentioned previously, this concentration is considered as questionable as the compound is detected at a very low concentration only in the dissolved sample.

Aberjona River - On-Site/Organics - SW-2 is located on the West Branch of the Aberjona River downstream of SW-1 and the East and West Hide Piles. SW-4 is located on the Northern Branch of the Aberjona which receives flow from the northeast corner of the Site. SW-17 is located downstream of the confluence of these two streams. SW-8 is located at the southeast edge of the Site and measures the surface-water quality from the I-93 drainway as it enters Phillips Pond. During the August 1990 sampling round, the I-93 drainway was dry. Thus, the sample at SW-8 represents the surface-water quality of Phillips Pond.

Di-n-butylphthalate was also detected in dissolved samples at all the on-site surface-water stations with concentrations of 2 µg/L at SW-2, 5 µg/L at SW-4, 6 µg/L at SW-17 and 1 µg/L at SW-8. Among organic compounds, acetone was detected at the highest concentration (20 µg/L at SW-2). Acetone was also detected in a duplicate sample collected at SW-8 at a concentration of 3 µg/L. Methylene chloride was detected at SW-4 at 2 µg/L.

Aberjona River - Downstream/Organics - Organic constituents detected at downstream stations on the Aberjona River flow system include detections of di-n-butylphthalate in the dissolved samples of SW-5 (7 µg/L), SW-12 (20 µg/L) and SW-14 (4 µg/L). Five other organic compounds were also detected at SW-14 including:

- methylene chloride, 8 µg/L
- bis(2-ethylhexyl)phthalate, 1 µg/L
- diethylphthalate, 3 µg/L
- diethylphthalate (dissolved) 2 µg/L
- di-n-butylphthalate, 1 µg/L
- n-nitrosodiphenylamine, 1 µg/L
- n-nitrosodiphenylamine (dissolved), 1 µg/L

These downstream stations (i.e., SW-5, SW-12, SW-14) on the Aberjona River measure surface-water quality downstream of previously discussed on-site stations (i.e., SW-2, SW-4, SW-17, and SW-8). Specifically, the relationships of these downstream stations to on-site stations are SW-5, located approximately one-third mile downstream of SW-17 (on Commerce Way) and measures surface-water conditions of the combined flow from the North, West, and South Branch of the Aberjona River; SW-12, located on a channeled section of the Aberjona River, approximately one-half mile downstream of SW-5 and includes no major new tributaries; and SW-14, located at the very south edge of the Study Area includes flow from both the Aberjona flow system (the east side of the Site) and Hall's Brook (the west side of the site).

Aberjona River - Upstream Site Boundary/Inorganics - Regarding inorganic surface-water quality, arsenic was not detected in either the total or the dissolved upstream surface-water sample collected at SW-1. Both chromium and lead were detected in the total metal analysis at 0.0036 mg/L and 0.0022 mg/L. Both of these values are considered estimates as they are below the CRDL.

<u>Aberjona River - On-Site/Inorganics</u> - Arsenic, chromium and lead were all detected in the on-site surface-water sample collected at SW-2. Concentrations were 0.0245 mg/L and 0.0406 mg/L for dissolved and total arsenic, respectively; 0.0039 mg/L for total chromium and 0.0030 for total lead. These arsenic concentrations are the highest detected in surface-water samples, while both the chromium and lead concentrations are below the CRDL and therefore considered estimated. Of the three metals, only total lead was detected at SW-4 at an estimated value of 0.0042 mg/L.

At SW-17, arsenic, chromium and lead were detected. Arsenic was detected at 0.0175 mg/L and 0.0296 mg/L for the dissolved and total samples, respectively. Total chromium and total lead were detected at respective concentrations of 0.0034 mg/L and 0.0063 mg/L.

At on-site station SW-8, in Phillips Pond, only total arsenic and total lead were detected. Both values were estimated at 0.0020 mg/L for arsenic and 0.0037 mg/L for lead.

<u>Aberjona River - Downstream/Inorganics</u> - Inorganic analytes detected in surface water at the downstream location SW-5, include dissolved and total arsenic (0.0138 mg/L and 0.0151 mg/L, respectively), and total lead at an estimated concentration of 0.0029 mg/L. Further downstream at SW-12, only dissolved arsenic is detected at a concentration of 0.0111 mg/L and total lead at an estimated concentration of 0.0036 mg/L.

Arsenic, chromium, and lead were all detected in the downstream location of SW-14, which includes surface water from Hall's Brook. Dissolved and total arsenic concentrations were 0.0072 mg/L and 0.0139 mg/L. Total chromium was detected at an estimated concentration of 0.0063 mg/L, while total lead was detected at 0.0059 mg/L.

Organic compounds in Aberjona River surface-water samples occurred at concentrations close to detection limits, with the exception of 20 μg/L of acetone at SW-2.

Arsenic, chromium and lead were not detected at all sampling locations, but at least one of the three metals was detected in upstream, on-site, and downstream samples. Arsenic was detected at six of the nine (SW-2, SW-5, SW-8, SW-12, SW-14, and SW-17) sampling locations. Both dissolved and total arsenic occurred at the highest concentrations detected in surface-

water samples at SW-2. Lead was detected in all Aberjona River samples, though often at concentrations below the CRDL and only as a total metal. Chromium occurred also only as a total metal and only at three locations (SW-1, SW-2, and SW-14).

Surface-water stations on the west side of the Site are located on drainage areas that flow into or are within the Hall's Brook Holding Area. These stations have been divided up into the upstream Site boundary (SW-6), on-site (SW-7, SW-15, SW-10, SW-16), and downstream (SW-9, SW-11, SW-13, and SW-14) groups as in the previous discussion of the Aberjona River surface-water quality.

Hall's Brook - Upstream Site Boundary/Organics - Upstream station, SW-6, located at the west side of the Site on an unnamed tributary had two organic compounds detected, namely chlorobenzene at 2 μg/L and di-n-butylphthalate at a dissolved concentration of 3 μg/L.

Hall's Brook - On-Site/Organics - On-site station, SW-7, located at the north end of the New Boston Street Drainway, had seven organic compounds detected. These include:
- 1,2-dichloroethane, 6 μg/L
- methylene chloride, 7 μg/L
- toluene 2, μg/L
- trichloroethene 6, μg/L
- bis(2-ethylhexyl)phthalate (total), 2 μg/L
- bis(2-ethylhexyl)phthalate (dissolved), 1 μg/L
- di-n-butylphthalate (dissolved), 3 μg/L
- phenol (dissolved), 1 μg/L

On-site surface-water stations also include SW-15, located south of the confluence of the unnamed tributary and the New Boston Street Drainway; SW-10, located on Hall's Brook (downstream of SW-15 but upstream of the Hall's Brook Holding Area); and SW-16, located on the Atlantic Avenue Drainway, which flows into the northern end of Hall's Brook Holding Area. No surface-water sample was collected at SW-16 during the August 1990 sampling round due to dry conditions.

Methylene chloride and bis(2-ethylhexyl)phthalate were both detected at SW-15 at respective concentrations of 7 μg/L and 4 μg/L. These, plus the following six compounds were detected at SW-10:

- chlorobenzene, 1 μg/L
- methylene chloride, 7 μg/l
- toluene, 2 μg/L
- trichloroethene, 3 μg/L
- bis(2-ethylhexyl)phthalate (total), 5 μg/L)
- di-n-butylphthalate (dissolved), 4 μg/L

Hall's Brook - Downstream/Organics - Downstream surface-water stations include SW-9, SW-11 and SW-13, which are located at the north and south end of the Hall's Brook Holding Area pond. SW-14, which includes discharge from both Hall's Brook and Aberjona River before flowing off-site, is also a downstream surface-water station.

A number of organic compounds were detected at each of these downstream surface-water stations. These compounds and their respective concentrations are listed below by surface-water station.

Organic compounds detected at SW-9:

- 1,1-dichloroethane, 3 μg/L
- 1,2-dichloroethene, 11 μg/L
- methylene chloride, 7 μg/L
- trichloroethene, 11 μg/L
- bis(2-ethylhexyl)phthalate (filtered), 3 μg/L
- di-n-butylphthalate (filtered), 5 μg/L
- n-nitrosodiphenylamine (filtered), 1 μg/L

Organic compounds detected at SW-11:

- 1,2-dichloroethene, 2 μg/L
- methylene chloride, 8 μg/L
- 1,1,1-trichloroethane, 4 μg/L
- trichloroethene, 3 μg/L

- total xylenes, 1 μg/L
- bis(2-ethylhexyl)phthalate, 12 μg/L
- butylbenzylphthalate, 2 μg/L
- diethylphthalate, 3 μg/L
- n-nitrosodiphenylamine, 1 μg/L
- diethylphthalate (dissolved), 3 μg/L
- di-n-butylphthalate (dissolved), 11 μg/L
- n-nitrosodiphenylamine (dissolved), 1 μg/L

Organic compounds detected at SW-13:
- 1,2-dichloroethene, 2 μg/L
- methylene chloride, 8 μg/L
- 1,1,1-trichloroethane, 9 μg/L
- diethylphthalate, 3 μg/L
- diethylphthalate (dissolved), 2 μg/L
- di-n-butylphthalate (dissolved), 6 μg/L

Organic compounds detected at SW-14:
- methylene chloride, 8 μg/L
- bis(2-ethylhexyl)phthalate, 1 μg/L
- diethylphthalate, 3 μg/L
- di-n-butylphthalate, 1 μg/L
- n-nitrosodiphenylamine, 1 μg/L
- diethylphthalate (dissolved), 2 μg/L
- di-n-butylphthalate (dissolved), 4 μg/L
- n-nitrosodiphenylamine (dissolved), 1 μg/L

Methylene chloride, diethylphthalate and n-nitrosodiphenylamine were detected at all of the Hall's Brook downstream surface-water stations. The greatest number (eleven) of different organic compounds were detected at SW-11, though not at higher concentrations than seen at the other locations. In summary, organic compounds range from 1 μg/L to 11 μg/L in upstream Site boundary, on-site, and downstream surface-water stations.

<u>Hall's Brook - Upstream/Inorganics</u> - Inorganic analytes detected in the upstream surface-water station SW-6 for Hall's Brook include; dissolved and total arsenic (0.0114 mg/L and 0.0179 mg/L), total chromium (0.0116 mg/L) and total lead (0.0022 mg/L).

<u>Hall's Brook - On-Site/Inorganics</u> - Inorganic concentrations for on-site station SW-1 included detections of dissolved arsenic (0.0027 mg/L) and total chromium (0.0626 mg/L). Both of these values are estimated (below the CRDL). Dissolved and total arsenic (0.0063 mg/L and 0.0151 mg/L) and total chromium (0.0303 mg/L) were detected at SW-15. All three analytes were detected at SW-10 at the following concentrations: dissolved and total arsenic (0.0035 mg/L an 0.0082 mg/L), total chromium (0.0205 mg/L); and total lead (0.0086 mg/L).

The downstream surface-water samples also contained arsenic, chromium and lead. These concentrations are listed below, following an upstream (off-site) to downstream sequence.

	SW-9	SW-11	SW-13	SW-14
Dissolved Arsenic (mg/L)	0.0077	0.0054	0.0056	0.0072
Total Arsenic (mg/L)	0.0081	0.0089	ND	0.0139
Total Chromium (mg/L)	0.0049	ND	0.0049	0.0063
Total Lead (mg/L)	0.0043	0.0032	0.0031	0.0059

3.3.2.2.3 Summary of Surface-Water Sampling Results

Surface-water samples collected in Hall's Brook and the Aberjona River showed several general trends (Plate 22). Organic compounds were detected at generally low concentrations, with the highest concentration being 20 μg/L of acetone (SW-2). Many of the compounds detected were at detection limits and/or considered common lab contaminants (i.e., acetone, methylene chloride, toluene and common phthalate esters). No benzene or toluene was detected in surface water on-site.

Arsenic, chromium, and lead were the most widely distributed and frequently detected inorganic constituents at the Site. Arsenic was detected in either the dissolved or total analyses

of thirteen of the fifteen sample locations with concentrations for total arsenic ranging from 2.0 μg/L (SW-8) to 40.6 μg/L (SW-2) and for dissolved arsenic from 2.7 μg/L (SW-7) to 24.5 μg/L (SW-2).

Chromium and lead were only detected as total metals. Samples collected in the New Boston Street Drainway/Hall's Brook drainage at the western portion of the Site exhibited the highest total chromium levels ranging from 20.5 μg/L (SW-10) to 62.6 μg/L (SW-7). These concentrations may be associated with the multi-colored soils located in the vicinity of SW-7. Total lead was detected in thirteen of the fifteen samples collected at concentrations of 2.2 μg/L (SW-1 and SW-6) to 8.6 μg/L (SW-10).

3.4 Stream-Sediment Investigation

The objective of the stream-sediment investigation was to evaluate the nature and extent of organic and inorganic constituents in sediments of the surface-water drainage system on-site, and within the Study Area. To accomplish this objective, stream-sediment data were evaluated in conjunction with hydrogeological and surface-water data developed as part of the GSIP RI. In addition, stream sediment data developed during the PDI (Task SW-1), were also evaluated. The following data sets were employed in this investigation:

- GSIP RI surface-water data collected July 31, 1990 through August 3, 1990;
- GSIP RI stream-sediment data collected July 31, 1990 through August 3, 1990;
- PDI Task SW-1, stream-sediment data collected May through June 1990.

3.4.1 Nature and Extent of Migration

To evaluate the nature and extent of organic and inorganic compounds in surface-water drainages within the Study Area, stream sediments were sampled during low flow (July 31 through August 3, 1990) conditions at the 17 surface-water observation locations (SW-1 through SW-17) shown on Plate 1. These sediment samples were designated as SED-1 through SED-17. In addition, a core (CORE 1) was obtained at the location where the Hall's Brook Holding Area pond discharges into the wetland to the south. (Plate 1) to provide information regarding depositional history. This location was selected in concurrence with the USEPA and their representative (NUS). The core was analyzed for TCL compounds and TAL metals. Stream-

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sediment data were also developed as part of the PDI program by Golder Associates Inc. and summarized in the report titled "Pre-Design Investigation Task SW-1, Extent of Hazardous Substances in Wetlands and Surface Water Sediments, Interim Final Report, September 1990". These data were incorporated into the evaluation of stream-sediment quality to meet the objective of the GSIP.

Also as part of this task, trunk sewer sediments were to be sampled concurrent with the discharge sampling. As previously mentioned, sediments were not present in the trunk sewer lines during the April 24 through April 26, 1990 sewer sampling, hence sewer sediment sampling was not performed.

The analytical program for the GSIP RI stream-sediment sampling was performed by Enseco-ERCO Laboratory (ERCO) (Cambridge, Massachusetts). Radian Corporation, (Austin, Texas) performed analyses for organo-tin, organo-mercury, iron oxide, manganese oxide and Fe^{+2}. Analytical data for the stream sediments are provided in Appendix C. The stream-sediment data were validated according to USEPA Region 1 guidelines presented in "Functional Guidelines for Evaluating Organic Analyses, November 1989" and "Functional Guidelines for Evaluating Inorganic Analyses, November 1989". Procedures outlined in the GSIP RI Work Plan were also followed. The data validation documentation is provided in Appendix D.

The stream-sediment data were entered into a computer database (dBase III+) to facilitate the retrieval and evaluation of the data. The entire database was then examined to determine the nature and extent of inorganic and organic compounds in the stream sediments.

PDI Task SW-1 sediment samples were collected during May and June, 1990 in upstream and on-site locations (Plates 19-21). These samples were collected as cores (0-3 feet) and locations at some transect samples were collected (left, middle, right) perpendicular to the stream bed. Arsenic, chromium and lead were analyzed at all locations, while organic compounds and TAL metals were only analyzed at selected depths and locations (Golder Associates, 1990).

In order to use these PDI data in a manner that data could be compared with the GSIP RI stream-sediment data, the following practices were followed. Arsenic, chromium and lead concentrations are taken from the samples at 0-6 inch depth. When left, middle and right samples were collected, producing multiple concentrations, these concentrations were averaged and presented as one concentration.

The types and extent of constituents present at upstream Site boundary, on-site, and downstream sampling locations (SW-1 through SW-17) for both the Aberjona River drainage area (eastern section of Site) and Hall's Brook drainage area (western section of Site) were identified to determine what impacts to stream sediments may be attributed to the Site, if any.

The upstream Site boundary stream-sediment sampling locations were:

Hall's Brook	Aberjona River
SW-6	SW-1
	SW-3

Downstream sampling locations were given that designation since they are located downstream of the Site. Sampling locations were designated as "upstream" if their location was upstream of on-site influences. Thus SW-6 is located on an Unnamed Tributary to the New Boston Street Drainway and flows from the west where the Woburn Municipal Landfill is located. SW-1 is located directly downstream of the culvert leading from the South Pond to the Lower South Pond. SW-3 is located at the far northeast corner of the Site, at the north end of the I-93 Drainway.

The on-site stream-sediment sampling locations were:

Hall's Brook	Aberjona River
SW-7	SW-2
SW-10	SW-4
SW-15	SW-8
SW-16	SW-17

Sampling locations were designated as onsite if they were located on the Site or their characteristics more closely resembled the adjacent sampling group. For instance, SW-10 is designated an "on-site" sampling location even though it is not located on-site. However, the physical characteristics of this sampling sites more closely resemble SW-15 than the downstream locations of SW-11 and SW-13 in Hall's Brook Holding Area.

The downstream stream-sediment sampling locations are:

Hall's Brook	Aberjona River	Both
SW-9	SW-5	SW-14
SW-11	SW-12	
SW-13		

In addition, CORE 1 in the Hall's Brook Holding area is considered downstream.

3.4.1.1 Nature of the Constituents Detected

The stream-sediment analytical data, from the 17 surface-water monitoring stations within the Study Area, were used to determine the extent, types and amounts of constituents detected. The spatial distribution of constituent concentrations was compared to surface-water and ground-water analytical data to assess the relationship between inorganic and organic compounds in these media and the stream-sediments. Review of the dissolved oxygen concentrations presented in Table 3-13 indicates that anoxic conditions were not recorded at any location. It is therefore unlikely that metal release from sediments into overlying surface waters occurs.

Organic compounds detected in upstream Site boundary, on-site, and downstream locations of the Aberjona River drainage areas and Hall's Brook drainage areas are summarized in Tables 3-20 and 3-21.

No pesticides or PCBs were detected in sediment samples collected during the GSIP. However, the analyses were performed outside of the holding times and the data was validated

as unusable in all samples except SED-3, SED-4 and SED-5. PDI SW-1 samples did contain the pesticide 4,4'-DDE (48 μg/kg) from the chromium lagoons and Arochlor-1248 (400 μg/kg) from the South Pond between the East and West Hide Piles.

During the GSIP RI, methylene chloride was also detected in stream-sediment samples from the Aberjona River.

GSIP RI stream-sediment samples included both phthalates and polynuclear aromatic hydrocarbons (PAHs). TAL metals detected in all of the seventeen samples included aluminum, arsenic, barium, calcium, chromium, cobalt, copper, iron, lead, magnesium, manganese, potassium, vanadium and zinc.

Trichloroethene and trans-1,2-dichloroethene were detected in stream-sediment samples collected during the GSIP RI. Other VOCs detected in stream-sediment samples included; acetone, benzene, chlorobenzene, 1,2-dichloroethane, ethylbenzene, methylene chloride, toluenes and xylenes.

VOCs detected in samples collected in the Aberjona River drainage included (maximum values listed); acetone (79 μg/kg), benzene (26 μg/kg), methylene chloride (56 μg/kg), toluene (1,200 μg/kg), xylene (4 μg/kg), chlorobenzene (27 μg/kg), 2-butanone (21 μg/kg), and ethylbenzene (2 μg/kg). Arochlor-1248 (400 μg/kg) was detected in the South Pond between the East and West Hide Piles.

Three VOCs were detected in PDI Task SW-1 samples collected within Hall's Brook drainage area. Acetone (69.7 μg/kg), chlorobenzene (9.3 μg/kg) and toluene (3.7 μg/kg) were detected in a stream sediment sample (PDI Task SW-1 sample 006), collected in the New Boston Street Drainway which is a tributary of Hall's Brook. These data are consistent with GSIP RI sample results for the same area (SW-6) where concentrations of acetone (230 μg/kg), chlorobenzene (440 μg/kg) and toluene (250 μg/kg) were detected. The pesticide 4,4'-DDE (48 μg/kg) was detected in the chromium lagoons.

Arsenic, chromium and lead were detected in nearly all of the samples collected during the PDI. Concentrations were generally lower in upgradient areas of the Site and increased relative to proximity to known source areas (i.e. hide piles, arsenic pit and chromium lagoons).

In summary, stream-sediment samples collected in the Aberjona River drainage area show fewer detected analytes and lower concentrations upstream, increase with proximity to the Site, and while present in sediments downstream, are seen in decreasing concentrations with distance from the Site.

A comparison of the surface-water and stream-sediment data indicates that the phthalate and PAH compounds were detected primarily in the stream-sediment samples. The phthalate and PAH compounds are essentially ubiquitous within the Study Area, and, tend to be more readily adsorbed onto the fine grained stream sediments present. Phthalate and PAH compounds have a strong affinity for organic material (humic and fulvic acids). However, in most soil-water systems these macromolecules are not mobile. The molecules tend to be adsorbed onto the surface of soil particles (Landrum et al., 1984).

Of the semi-VOCs detected the phthalate compounds are used as plasticizers, n-nitrosodiphenylamine is an accelerator in vulcanizing rubber, and the PAH compounds are associated with coal tar.

3.4.1.2 Extent of the Constituents Detected

The data developed during the GSIP RI were evaluated with the PDI stream-sediment results as discussed in the previous section. The evaluation of the combined PDI and GSIP RI data was performed to assess the extent of organic and inorganic compound migration in surface-water drainages of the Study Area.

VOCs detected in the stream sediments were mapped (Plate 17). Several types of PAH and phthalate compounds were detected in the stream sediments upstream, on-site, and downstream of the Aberjona and Hall's Brook flow systems. The concentrations of total semi-VOCs detected during the GSIP RI and PDI Task SW-1, were graphed to depict the distribution of the concentrations of these compounds in the sediments of the surface-water

drainages (Figure 11). The concentrations of organic compounds in the stream sediments were then compared to the concentrations of these compounds in surface water and ground water to provide a comprehensive understanding of their transport within the Study Area.

The concentrations of arsenic, chromium, and lead recorded in stream-sediment samples during the GSIP RI and PDI Task SW-1 are depicted in Plates 19, 20 and 21. These metals were selected for mapping based upon their frequency of detection and concentrations. Concentrations of arsenic in stream sediments detected during the GSIP RI were graphed to depict the distribution of these compounds in the surface-water drainages (Figure 10).

In addition, arsenic, chromium and lead stream-sediment concentrations for the Aberjona River were plotted versus distance from the Lower South Pond PDI Task SW-1 sample number 028 to Mishawum Road (SW-14) (Figures 12 through 14).

Aberjona River - Upstream Site Boundary/Organics - Stream-sediment samples were collected at two upstream locations from the Aberjona River drainage area, SW-1 and SW-3. The SW-1 location is located at the northern end of the Lower South Pond, directly south of the culvert discharging water from Upper to Lower South Pond. While the Lower South Pond is located between and immediately adjacent to the East and West Hide Piles, the SW-1 location is considered to be upstream of these on-site sources. SW-3 is located at the northern end of the I-93 drainway, a portion of which flows west into the North Branch of the Aberjona River.

Two volatile organic compounds were detected in SED 1, methylene chloride (7 μg/kg) and toluene (6 μg/kg). These values are comparable to the concentration of 7 μg/kg detected in SED-3. As both methylene chloride and toluene are common laboratory contaminants and these concentrations are close to the CRQL of 5 μg/kg, it is questionable if these compounds are present in sediments from these locations. Bis(2-ethylhexyl)phthalate was the only SVOC detected at the SW-1 location. No SVOCs were detected in SED-3.

Two upgradient samples collected during PDI Task SW-1 were analyzed for volatile organic compounds. No VOCs were detected in Task SW-1 sample number 42, collected in the South

Pond and north of SED-1. Acetone, at 49 μg/kg, was the only VOC detected in Task SW-1 sample number 49, collected in a wetland adjacent to the northern branch of the Aberjona River (Plate 17).

Aberjona River - On-Site/Organics - On-site sediment samples for the Aberjona River drainage area were collected at SW-2, SW-4, SW-17 and SW-8. SW-2 is located within the West Branch of the Aberjona River, downstream of the SW-1 location and the East and West Hide Piles. SW-4 is located on the Northern Branch of the Aberjona. SW-17 is located downstream of the confluence of the West and North Branch of the Aberjona River. SW-8 is located where the I-93 Drainway enters Phillips Pond.

VOCs detected include acetone in SED-17 (22 μg/kg) and methylene chloride in SED-2 (6 μg/kg), SED-4 (5 μg/kg), SED-17 (4 μg/kg) and SED-8 (7 μg/kg). These concentrations are close to those quantified at upstream locations. Fourteen SVOCs were detected in on-site stream-sediment samples. Eleven of the fourteen compounds were detected in SED-2, ranging from 1,500 μg/kg for both fluoranthene and pyrene to 320 μg/kg for anthracene. Six SVOCs were detected in SED-17, ranging from 1,300 μg/kg for benzoic acid to 110 μg/kg for bis(2-ethylhexyl)phthalate. No semi-volatile compounds were detected in either SED-4 or SED-8. The organic compounds, their concentrations, and samples they were detected in are listed in Table 3-20.

Six of the PDI Task SW-1 sediment samples collected in the Lower South Pond were analyzed for volatile organic compounds. Eight compounds were detected and the highest concentrations of each were acetone (79 μg/kg), benzene (26 μg/kg), chlorobenzene (27 μg/kg), methylene chloride (56 μg/kg), toluene (1,200 μg/kg), ethylbenzene (2 μg/kg), xylene (5 μg/kg), and 2-butanone (21 μg/kg). Acetone was also detected in the two pond and stream samples collected adjacent to the East Central Hide Pile at 22 μg/kg in sample number 21, and 28 μg/kg in sample number 57.

Aberjona River - Downstream/Organics - Downstream sediment samples for the Aberjona River flow system were collected at SW-5, SW-12 and SW-14. Three volatile organic compounds were detected in SED-5; 2-hexanone (9 μg/kg), methylene chloride (4 μg/kg) and 4-methyl-2-pentanone (2 μg/kg). Thirteen semi-volatile compounds were also detected

in SED-5, ranging from 200 μg/kg for anthracene to 1,900 μg/kg for benzo(b)fluoranthene and 1,900 μg/kg of benzo(k)fluoranthene. SW-5 is located downstream of all the Aberjona River upstream and on-site surface-water stations.

SED-12, which was collected approximately one half mile downstream of SW-5 had three volatile organic compounds detected; methylene chloride (4 μg/kg), tetrachloroethene (3 μg/kg), and trichloroethene (2 μg/kg). Fifteen semi-volatile organic compounds were detected in SED-12, ranging from dibenzofuran at 540 μg/kg to fluoranthene at 24,000 μg/kg.

SW-14, the most southerly and downstream station is just below the confluence of the Aberjona River and the Hall's Brook Holding Area. The only volatile organic compound detected in SED-14 was methylene chloride at a concentration of 2 μg/kg which is very close to the detection limit. Thirteen semi-volatile organic compounds were detected in this stream-sediment sample ranging from 290 μg/kg of indeno(1,2,3-cd)pyrene to 3,300 μg/kg for 3,3'-dichlorobenzidine.

In summary, organic compounds detected in stream-sediment samples from the Aberjona River flow system had concentrations of VOCs ranging from 2 μg/kg to 99 μg/kg, with the exception of toluene concentrations of 1,200 μg/kg and 650 μg/kg collected in the Lower South Pond. SVOCs were not detected in stream sediments collected on the east side of the Site (SED-3, SED-4 and SED-8). Semi-volatile organic compounds were detected in sediments collected on-site. These compounds are also detected in downstream sediment samples collected at concentrations ranging from 540 μg/kg for dibenzofuran to 24,000 μg/kg for fluoranthene at SED-12, and then decreasing to concentrations ranging from 290 μg/kg for benzo(g,h,i)perylene to 3,300 μg/kg for 3,3'-dichlorobenzidine further downstream at SED-14.

Aberjona River - Upstream Site Boundary/Inorganics - Stream-sediment samples collected during the GSIP RI were analyzed for TAL metals and tin. PDI Task SW-1 samples collected at 0-6 inch depth were analyzed for arsenic, chromium, and lead. These three metals concentrations are shown in Plates 19 through 21.

Upstream Aberjona River sediment samples were collected at SED-1 and SED-3. The metal concentrations for arsenic, chromium and lead are presented below.

	SED-1	SED-3
Arsenic (mg/kg)	4.8	29.4
Chromium (mg/kg)	28.6	30.4
Lead (mg/kg)	11.6	26.7

Task SW-1 sediment samples collected in upstream locations show the following ranges of concentrations: arsenic, 1.1 mg/kg to 69.6 mg/kg; chromium, 6.9 mg/kg to 61.7 mg/kg; and lead 10.1 mg/kg to 487 mg/kg.

The lead concentration of 487 mg/kg was detected in sample number 49, collected in a wetland in the northeast corner of the Site.

Aberjona River - On-Site/Inorganics - Arsenic, chromium and lead were detected in all of the on-site stream-sediment samples collected along the Aberjona River flow system. In addition, mercury which was detected at SW-2 (0.100 mg/kg), is within background levels for soils (Shacklette and Boerngen). Concentrations for arsenic, chromium and lead at each station are presented below.

	SED-2	SED-17	SED-4	SED-8
Arsenic (mg/kg)	371	58.6	4.2	2.6
Chromium (mg/kg)	546	100	27.3	7.6
Lead (mg/kg)	212	116	28.7	5.3

The PDI SW-1 and GSIP data presented in Plates 19, 20 and 21 show that higher concentrations detected in samples collected in ponds and wetlands may be a function of the grain size of the samples. Finer grained sediments possess greater surface area per unit of mass upon which metals can be adsorbed in comparison to coarse grained sediments.

<u>Aberjona - Downstream/Inorganics</u> - Downstream sediment samples continue to decrease in concentration with distance from the Site. Sediment concentrations for arsenic, chromium and lead are listed sequentially from upstream to downstream locations below.

	(on-site)	(downstream)		
	SED-17	SED-5	SED-12	SED-14
Arsenic, mg/kg	58.6	12.5	9.4	20.6
Chromium, mg/kg	100	22.2	18.6	13.5
Lead, mg/kg	116	28.7	41	7.3

Generally, a decreasing trend is seen in metal concentrations in stream sediments along the Aberjona River. Stream and pond sediments had lower metal concentrations in upstream and upgradient Site locations than those detected on Site and downstream.

<u>Hall's Brook - Upstream Site Boundary/Organics</u> - Stream-sediment samples were collected at an upstream location in the Hall's Brook drainage at SED-6. Three volatile organic compounds were detected in SED-6 including acetone (230 μg/kg), chlorobenzene (440 μg/kg) and toluene (250 μg/kg). Four semi-volatile organic compounds were detected in SED-6: bis(2-ethylhexyl)phthalate (7,900 μg/kg), fluoranthene (1,200 μg/kg), phenanthrene (1,000 μg/kg) and pyrene (1,200 μg/kg).

<u>Hall's Brook - On-Site/Organics</u> - On-site stream-sediment samples for the Hall's Brook drainage were collected at SW-15, SW-10, and SW-16. These on-site sampling locations represent two different tributaries within the Hall's Brook Holding Area. SW-7, SW-15 and SW-10 are located on the New Boston Street Drainway/Hall's Brook tributary draining the far northwest corner of the Site. SW-16 is located in the Atlantic Avenue Drainway which drains the central portion of the Site.

VOCs detected in on-site sediment samples at the locations discussed above include 1,2-dichloroethene (2 μg/kg) and trichloroethene (3 μg/kg) in SED-7; methylene chloride (6

μg/kg), tetrachloroethene (11 μg/kg), and trichloroethene (3 μg/kg) in SED-15; methylene chloride (3 μg/kg) and tetrachloroethene (2 μg/kg) in SED-10; and acetone (170 μg/kg) in SED-16.

Only one SVOC, bis(2-ethylhexyl)phthalate, was detected in SED-10 (290 μg/kg) and in SED-7 (94,000 μg/kg). Seventeen different semi-volatile organic compounds were detected in SED-15. Concentrations ranged between a high of 5,200 μg/kg for bis(2-ethylhexyl)phthalate to a low of 100 μg/kg for n-nitrosodiphenylamine. Thirteen semi-volatile organic compounds were detected in SED-16. They ranged between 1,700 μg/kg for anthracene to 27,000 μg/kg for benzo(b)fluoranthene.

One PDI Task SW-1 sample collected in the New Boston Street Drainway was analyzed for VOCs. Two VOCs were detected in the left, middle and right samples, acetone (54 to 96 μg/kg) and chlorobenzene (7 to 18 μg/kg).

Hall's Brook - Downstream/Organics - The Hall's Brook drainage area downstream sediment-sampling locations include SED-9, SED-11, SED-13 and SED-14. CORE 1 (collected approximately 50 feet downstream of SW-13) is also a downstream sediment sample. SW-9, SW-11 and SW-13 are all located in the Hall's Brook Holding Area Pond. These samples (SW-9, SW-11, and SW-13) are finer grained (87-100 percent silt and clay) than the other stream-sediment samples (less than 46 percent silt and clay). As a result of the finer grained nature of the Hall's Brook Holding Area sediments, organic and inorganic compounds are, in general, present in higher concentration than the other stream-sediment samples. These higher concentrations are attributed to the high surface area upon which organic compounds and metals can sorb. Additionally, as sediments settle out in the slower flowing waters of the pond, the area is acting not only a holding area for stream flow from the north, but also sediments transported in the stream flow from upstream locations.

Volatile organic compounds detected in the stream-sediment samples collected in the Hall's Brook Holding Area were as follows. The four compounds detected in SED-9 included benzene (2100 μg/kg), 1,2-dichloroethane (28 μg/kg), ethylbenzene (40 μg/kg) and total xylenes (150 μg/kg). Three volatile organic compounds were detected in SED-11 included

acetone (470 μg/kg), benzene (160 μg/kg) and 2-butanone (47 μg/kg). Finally, five volatile organic compounds were detected in SED-13 included acetone (400 μg/kg), benzene (200 μg/kg), 2-butanone (71 μg/kg), ethylbenzene (9 μg/kg) and methylene chloride (39 μg/kg).

Semi-volatile organics were also detected in these samples and are listed on Table 3-21. The number of compounds detected, and range of concentrations for each sampling location, are as follows. Thirteen semi-volatile organic compounds were detected in SED-11 and ranged from 1,500 μg/kg for anthracene to 78,000 μg/kg for bis(2-ethylhexyl)phthalate. Ten semi-volatile organic compounds were detected in SED-13 and ranged from 1,000 μg/kg of benzo(a)pyrene to 29,000 μg/kg of bis(2-ethylhexyl)phthalate.

Due to high detection limits in SED-9, ranging from 1,800 to 8,900 μg/kg, no SVOCs were detected. The detection limits for the SVOCs at SED-9 are shown on Table 3-22.

SW-14, the most southerly and downstream station is just below the confluence of the Aberjona River and the Hall's Brook Holding Area. The only VOC in SED-14 was methylene chloride (2 μg/kg), detected at a concentration close to the detection limit. Thirteen semi-volatile organic compounds were detected in this stream-sediment sample with ranges from 290 μg/kg for indeno(1,2,3-cd)pyrene and benzo(g,h,i)perylene to 3,300 μg/kg for 3,3'-dichlorobenzidine.

Hall's Brook - Inorganics - Maximum concentrations for 21 of the 24 metals analyzed during the GSIP RI were found in stream samples collected within the Hall's Brook drainage area.

Maximum concentrations were antimony (375 mg/kg), barium (462 mg/kg), lead (4210 mg/kg), mercury (9.5 mg/kg), silver (13.6 mg/kg) and thallium (38.4 mg/kg) in the sediment sample collected at SW-7. SED-7 was the only sample in which thallium was detected.

Arsenic, chromium and lead concentrations detected in stream sediments are shown on Plates 19, 20 and 21. A discussion of metal occurrence follows.

Hall's Brook - Upstream Site Boundary/Inorganics - Arsenic, chromium and lead concentrations in Hall's Brook upstream sampling location SW-1/001 and SW-6 are listed below.

	SW-1/001	SED-6
Arsenic (mg/kg)	16.5	154
Chromium (mg/kg)	234	95.4
Lead (mg/kg)	16.3	27.3

PDI Task SW-1 sample number 1 was collected at a wetland at the northern end of the New Boston Street Drainway, and is included as it is the most upstream sample collected on that tributary. Mercury was also detected at SED-6 (0.4 mg/kg).

Hall's Brook - On-Site/Inorganics - The metals listed below were also detected at on-site sampling locations; SED-7, SED-15, SED-10, and SED-16 at the concentrations listed below.

	SED-7	SED-15	SED-10	SED-16
Arsenic (mg/kg)	1580	511	170	928
Chromium (mg/kg)	331	118	32.1	140
Lead (mg/kg)	4210	346	315	354
Mercury, mg/kg	9.5	0.3	<0.1	<0.4

SED-15 sediment sample was collected downstream of sampling locations SW-6 and SW-7. Metal concentrations are lower than those in SED-7 but greater than those in SED-6. SED-16 was collected on-site in the Atlantic Avenue Drainway, which drains the central portion of the Site.

Hall's Brook - Downstream/Inorganics - Selected metal concentrations in on-site stream-sediment samples are listed below:

	SED-9	SED-11	SED-13	CORE 1 0.2' - 0.5'	SED-14
Arsenic (mg/kg)	9830	1750	1330	9.9	20.6
Chromium (mg/kg)	1090	529	382	13.9	13.5
Lead (mg/kg)	611	320	275	5.7	7.3
Mercury (mg/kg)	1.9	1.7	1.0	<0.1	<0.3

Arsenic concentrations plotted versus distance are shown in Figure 12. Downstream sediment samples first show an increase in metals concentrations as sediments from on-site settle out and are deposited in Hall's Brook Holding Area pond. A decline in concentrations is then seen as distance from the Site increases.

General Trends in Sediment Trace Metal Concentrations - As a general rule, trace element concentrations in sediment increase as grain size decreases due to an increase in the surface area/volume ratio as the particle size diminishes (Horowitz, 1991). Thus, it is important to recognize that the interpretation of *bulk* sediment concentration (i.e. mg/kg) can be strongly biased if the grain size distribution data are ignored. For this evaluation, data from both the GSIP RI (stations designated SW) and the PDI (stations designated SW-1) were utilized. It is thus important to note that the former investigation determined grain size while the latter did not.

Aberjona River Drainage Area - The relationship between the distance from Lower South Pond versus sediment metal concentration of arsenic, chromium, or lead are illustrated in Figure 12, 13, and 14, respectively. All three metals appear to correlate fairly well from station to station, indicating that grain size may be a significant factor with regard to bulk sediment concentrations. A "best fit" curve was plotted for each dataset, yielding a function which most closely approximates an exponential decay term. This observation is consistent with findings in the literature which state that physical and chemical processes (e.g., adsorbtion, complexation, precipitation) will remove metals from the water column, the particulate bound metals will ultimately be transported to the sediment, and sediment concentrations will generally decrease to near background levels within 300 to 1300 meters of a known source (Baudo *et al.*, 1990; NAS, 1977).

Hall's Brook Drainage Area - Only two samples were collected in the Unnamed Tributary, which flows east (toward the Site). If PDI station SW-1 006, taken at the confluence of this tributary and the New Boston Street Drainway, is included in the dataset for this stream, then the concentrations of arsenic and lead increase, while no trend is evident for chromium.

The New Boston Street Drainway, flowing south, differs from other Site locations in that the concentrations of chromium in sediment do not increase or decrease in proportion with arsenic

or lead. For locations selected within this stream, sediment concentrations for the arsenic and lead are proportional ($r = 0.97$), and generally decrease as one moves in either direction from GSIP RI location SW-7. For chromium, however, the concentrations are greater in the small wetland to the north and generally decrease in the direction of flow. Further south (SW-15 and SW-10), sediment chromium concentrations continue to decrease, while concentrations of arsenic and lead are variable (Plate 18).

The flow regime for the Atlantic Avenue Drainway is intermittent. Accordingly, samples taken within this area cannot be characterized as a true "sediment". This area has seen past industrial activity and, based on previous investigations, soils adjacent to this drainway were shown to exceed action levels for arsenic, chromium, and lead. With the exception of chromium, no clear trend in the data is evident as one moves in the direction of anticipated flow. Chromium increases closer to the proximity of the chromium lagoon, as expected. Arsenic and lead correlate very well within this dataset, indicating that the source is most probably lead arsenate and that bulk sediment metal concentrations (mg/kg) may be influenced by grain size.

The ponded portion of the Hall's Brook Holding Area receives runoff from Hall's Brook, the Unnamed Tributary, the New Boston Street Drainway, and the Atlantic Avenue Drainway. The deeper waters of the Hall's Brook Holding Area pond allow siltation of much of the suspended sediment that is present in the water column. Similar to observations made within the Aberjona River, arsenic, chromium, and lead concentrations decrease as a function of the distance moved downstream (away from the Atlantic Avenue Drainway) within the Hall's Brook Holding Area. At this time, it would be premature to draw conclusions based on the results of four sampling locations. If, however, the relationship seen within the Aberjona holds true for the Hall's Brook Holding Area, i.e. an exponential decrease in bulk sediment metal concentration versus downstream distance, then sediment concentrations south of the ponded area should also be expected to decrease to near background levels.

Because sediments sampled within the Hall's Brook Holding Area are depositional, they have a higher percentage of silt, clay, and total organic carbon than other substrates sampled within the Study Area (Table 3-19). Many of the matrix elements, such as aluminum and manganese, show similar concentrations as Site related metals (arsenic, chromium and lead). Interpreting

the data strictly on bulk sediment metal concentration, it would appear that the sediments within the Hall's Brook Holding Area have concentrations of metals such as cadmium, that exceed background concentrations. In natural soils and sediment, cadmium normally ranges between 0.1 to 1 ppm and is generally proportional to zinc as they have very similar colligative properties (Friberg *et al.*, 1986). This relationship also appears to hold true for the Hall's Brook Holding Area (Figure 15). It can be seen that there is a significant linear relationship between cadmium and zinc in these sediment samples (r = 0.94). Though it would not be prudent to draw any firm conclusions on a few data points, it can be deduced that: a) the amounts of cadmium and zinc are not markedly greater (possibly 2 to 3 fold) than concentrations found in natural sediment (Baudo, *et al.*, 1990); and b) the concentrations of cadmium and zinc most probably reflect the proportions of Cd/Zn in pyritic material that may be present in soils upstream of the Hall's Brook Holding Area ($\approx$ 1:157).

The above example is not intended to demonstrate that the Hall's Brook Holding Area contains near background concentrations of constituents of concern. The intent is to demonstrate that caution should be exercised in the interpretation of bulk sediment analyses, and that grain size distribution should not be ignored. Even in relatively pristine environments, trace metal concentrations will generally increase as grain size decreases.

As expected, the general trend seen for arsenic, chromium, and lead concentrations in sediment is to decrease as the downstream distance between the Site and the sampling stations increase. Metal concentrations in samples taken within streams that move through areas currently slated for remedial activity (e.g. New Boston Street Drainway, Atlantic Avenue Drainway) are generally higher than those taken in less disturbed (e.g. Upper South Pond, North Branch of Aberjona) areas.

3.4.1.3 Summary of Stream-Sediment Sampling Results

Chlorinated VOCs, phthalates, and PAHs were detected in sediment samples collected within the study area (Plate 23). Toluene was detected in sediment samples from the upstream boundary of the Site and on-site, but not in downstream samples. Benzene was detected in pond sediments, downstream (Hall's Brook Holding Area), and on-site (Lower South Pond), but not in stream sediments. Arsenic, chromium, and lead were the metals most frequently detected upstream, on-site, and downstream of the Site.

Analytical results of sediment from the farthest downstream surface-water sampling stations (SW-14, located just south of Mishawum Road) suggest that organic and inorganic compounds are not migrating off-site.

An order of magnitude decrease in organic and inorganic constituent concentration from the north end of Hall's Brook Holding Area (SW-9) to the south end of Hall's Brook Holding Area (SW-13) and then again to the confluence of Hall's Brook with the Aberjona River (SW-14) indicates that Hall's Brook Holding Area pond and wetland is effective at trapping organic and inorganic compounds transported (on fine-grained sediment) from upstream and preventing downstream migration of this sediment.

A similar trend is seen in the Aberjona River with decreasing arsenic, chromium, and lead concentrations with distance from the Site. Volatile organic compounds detected in on-site sediments are not detected downstream with the exception of methylene chloride which occurs in samples collected throughout the study area. Total semi-volatile organic compounds were detected at higher concentrations in downstream samples than in samples collected within the Site boundary.

3.5 Metals Mobility Study

The objective of the metals mobility study as outlined in the GSIP RI Work Plan, was to determine the factors that govern the mobility of arsenic, chromium, lead, and mercury in soil and ground water at the Site. Data developed during the GSIP RI and the PDI programs, as well as information reported in the literature, were evaluated to meet this objective. Specific tasks performed as part of the metals mobility study were:

- determination of the environmental mobility and fate of arsenic, chromium, lead, and mercury by evaluation of the literature, and existing database (Section 3.5.1);
- measurement of the critical parameters controlling the mobility of arsenic, chromium, lead, and mercury in ground water (Section 3.5.2);
- determination of the chemical species of arsenic, chromium, lead, and mercury present in ground water at the Site (Section 3.5.3); and
- evaluation of the current and future mobility of arsenic, chromium, lead, and mercury at the Site based on the information obtained above (Section 3.5.4).

3.5.1 Evaluation of the Literature and Database

This section provides a summary of the available literature, an evaluation of the geochemistry of these four metals in relation to the soil and ground-water database, and an assessment of the critical parameters that control metals mobility in soil and ground water at the Site. An analysis of the published literature on the semi-metal arsenic (As), and the metals chromium (Cr), mercury (Hg), and lead (Pb) in soils with similar physical and chemical properties to those of the Site, demonstrates that precipitation and sorption within these media may be a significant mechanism controlling metals mobility.

Variables controlling contaminant mobility at the Site include the ground-water flow rate, and the chemical reactions that control mineral solubilities, adsorption, and secondary reactions (e.g., coprecipitation) that affect aqueous composition. In addition, understanding the relationship between soil and ground-water metal distribution requires correlating the distribution of metal sources with the distribution of dissolved metals in the ground water, and the values of several critical geochemical parameters such as dissolved oxygen, chemical oxygen demand (COD), oxidation potential (Eh), and pH. The Eh and pH conditions are especially important because they often govern metal solubility in the soil/aquifer system (Adriano, 1986; Alloway, 1990; Brookins, 1987). With an understanding of the factors controlling contaminant transport, a range of remedial alternatives may be developed that will control migration.

With regard to the types of analyses performed and the geographic distribution of sampling locations, the most complete ground-water data set was collected during the GSIP RI program and Phase 1 of the PDI. Therefore these data have been used to interpret the aqueous geochemistry at the Site. Soil metal relationships were also evaluated using the Phase 2 soils data, PDI Task S-1 data, and PDI Task SW-1 data. Sewer, surface-water and stream-sediment data collected during the GSIP RI were also used to evaluate these ancillary routes of potential metal transport. Although soils, surface waters and sediments are important as metals sources, the emphasis in this section is placed on ground water because it is the primary transport route for metal migration.

Data from the GSIP RI and the PDI were used to develop a paradigm, or conceptual model, of the geochemical mechanisms controlling metals migration at the Site (Figure 16). Sections

3.5.1, 3.5.2, and 3.5.3 of this report summarize the geochemical mechanisms controlling metals mobility as determined by evaluation of data developed during Site investigations and based on the literature. Section 3.5.4 couples geochemical mechanisms, which appear to control metals mobility at the Site, with geochemical plume maps, compiled from Site-specific data, to demonstrate the validity of the conceptual geochemical model of the Site.

3.5.1.1 Background/Site History

Soil sampling conducted at the Site during the Phase 1 and Phase 2 investigations has identified the following locations at which the concentrations of priority pollutant metals in soil exceeds 100 μg/kg.

- Arsenic pit (11 acres).
- Chromium Lagoon (9.5 acres).
- Area West of MBTA railroad tracks (6.0 acres).
- Atlantic Avenue Drainway (2 acres).

The industrial processes utilized at the Woburn Site during the period 1853 to 1980 can account for the variety of metals in the soil and ground water. The distribution of these metals at the Site is complicated due to a combination of variable on-site waste disposal practices, the movement and subsequent replacement of hide bearing soils and the differential mobility of metals in the subsurface. The following section briefly reviews the manufacturing history of the Site in terms of the types of metals found on the property.

Period from 1853 to 1933

Arsenical pesticides manufactured at the Site may have included lead m-arsenate, monolead o-arsenate, trilead arsenate and calcium arsenate formulations beginning in, or about, 1892 (Thompson, 1973). In addition, magnesium and zinc arsenates may have been formulated from 1920 to 1930 and from 1920 on, respectively, as substitutes for lead arsenate. Several methylated arsenic compounds have been used as selective herbicides. However, it is unlikely that methyl species were manufactured at the Site because these formulations were not used prior to 1961 (National Academy of Sciences, 1977).

Pyrite was used at the Site during this period to make sulfuric acid (H_2SO_4), that was also used to formulate hydrochloric acid (HCl) and tin chloride (SnCl). In addition to providing potential sources of sulfate (SO_4), hydrogen sulfide (H_2S), chloride (Cl), and tin (Sn), pyrite degradation in the soil may have generated sulfuric acid. Pb and Zn are also present in pyrite mineral assemblages as the sulfides galena (PbS) and sphalerite (ZnS). In addition, As may be present as a minor impurity in pyrite (Barnes, 1979).

Dyes were also manufactured on the Site during the period from 1853 to 1933. The Phase 2 RI (Roux Associates, Inc., 1984) indicates that metals associated with this type of processing include Pb, Hg and Cr.

Period from 1933 to 1969

New England Chemical operated a factory that generated glue from raw animal hides and chrome tanned hides. This process utilized magnesium carbonate ($MgCO_3$), sodium hydroxide (NaOH), and H_2SO_4 to extract glue constituents from the hides. Consequently, the hides could be a potential source of Mg, SO_4, and alkalinity. In addition, the Hide Piles may be a source of Cr(VI) and/or Cr(III) to the aquifer, possibly migrating in solution as an organic complex (James and Bartlett, 1983).

Circa 1980

The Hide Piles were placed in their current locations. It is important to recognize that the hide piles were placed on top of the existing grade. Historical evidence also indicates that soils containing metals were placed on the pre-1931 grade long before the hide piles were developed. The Phase 2 RI (Roux Associates, Inc., 1984) provides the following estimates of the volume of buried hide material at the Site.

- East Hide Pile (3.2 acres, 125,000 yd^3)
- West Hide Pile (2.6 acres, 50,000 yd^3)
- East-Central buried hides (5.7 acres, 106,000 yd^3)
- South-Central Hide Pile (1.4 acres, 60,000 yd^3)

The hide piles represent a large source of organic material and, as evidenced by the presence of methyl mercaptan and hydrogen sulfide gas, have apparently induced extremely reducing conditions in the soil and the underlying ground water (Roux Associates, Inc., 1984). Thus,

in addition to acting as a Cr source, the hide piles generate reducing conditions in the ground water. Historical practices at the Site not only explain the potential sources of metals found in the soils and ground water, but have produced variations in the geochemical conditions that control metal migration.

3.5.1.2 pH and Eh conditions

To emphasize the importance of acidity and redox on metal transport, Eh-pH diagrams have been constructed using the ground-water data from the Site. The approximate Eh-pH limits for naturally occurring soil/ground-water systems, and the water stability limits are shown in Figure 17.

Eh-pH diagrams are used to illustrate environments where solid phases or minerals may precipitate in soil and ground-water systems (Pourbaix, 1966; Kotrly and Sucha, 1985; Smith and Martell, 1976; Lindsay, 1979; Brookins, 1986). In environments where dissolved species (i.e., anions and cations) predominate, metals are unlikely to be attenuated by precipitation reactions.

The boundary between an environment where a mineral precipitates and where dissolved species predominate represents the general location of a transition domain that exists between two adjacent domains, rather than an abrupt boundary. For example, if the Eh-pH conditions of soil or ground water fall near a phase boundary on an Eh-pH diagram, but in an environment where dissolved species predominate, precipitation may occur but should not be the predominant reaction in the system. However, even when solid phases are predicted to control solubility, the precipitation reaction may be hindered by kinetic factors, or even be misconstrued due to the presence of unanticipated species (e.g. organo-metallic complexes) not considered in the calculations. However, despite these inadequacies, Eh-pH diagrams provide valuable information pertaining to metal solubility controls in soil and ground-water data.

3.5.1.3 Iron and Sulfur

Iron (Fe) exists in two common valence states, the oxidized Fe(III) and the reduced Fe(II) form. Much of the Fe at the Site originates from spent pyrite (FeS_2) used to generate $H_2SO_4{}^\circ$.

In an oxidizing environment, the incongruent dissolution of remnant pyrite is facilitated by the presence of *Thiobacillus* to produce amorphous ferric hydroxide ($Fe(OH)_3$) and acid:

$$FeS_2 + 4.25\ O_2 + 2.5\ H_2O \rightleftarrows Fe(OH)_3 + 2H^+ + 2SO_4^{-2} \qquad \text{(Eq. 1)}$$
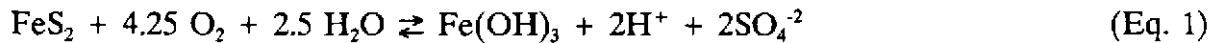
Precipitation of $Fe(OH)_3$ is an important reaction due to the strong affinity of this solid to remove other metals from solution by coprecipitation and/or adsorption. However, in the absence of oxygen and in a reducing environment near neutral pH (Figure 18) congruent dissolution of pyrite is likely, catalyzed by Fe(III) in the presence of bacteria (Nordstrom, 1977):

$$FeS_2 + 14Fe^{3+} + 8H_2O \rightleftarrows 15Fe^{+2} + 2SO_4^{-2} + 16H^+ \qquad \text{(Eq. 2)}$$
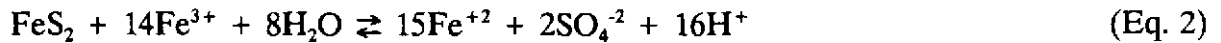
Ferrous ion is highly soluble under reducing, acidic to neutral pH conditions (Figure 18). Under normal atmospheric conditions it will oxidize rapidly (Figure 19) with a half life of 18 to 38 minutes at pH 6.8 (Sung and Morgan, 1980) and precipitate in the presence of oxygen:

$$Fe^{2+} + 3H_2O \rightleftarrows Fe(OH)_{3(s)} + 3H^+ + e^- \qquad \text{(Eq. 3)}$$

In addition to the Fe system, the sulfate/sulfide couple may also be used to qualitatively describe the redox state of a soil, sediment or ground water. As conditions become more reducing, aqueous sulfide forms through the reduction of sulfate mediated by organic matter (generalized by CH_2O), i.e.;

$$SO_4^{-2} + CH_2O + O_2 + 10H^+ + 8e^- \rightleftarrows H_2S + CO_2 + 5H_2O \qquad \text{(Eq. 4)}$$
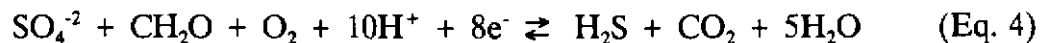
As aqueous sulfide concentrations increase, volatile hydrogen sulfide gas forms. The presence of detectable $H_2S_{(g)}$, methyl mercaptan (CH_3HS), dissolved iron, and low dissolved oxygen concentrations in areas downgradient from the hide piles are all indicative of a reducing environment in these areas.

Superimposing the Eh-pH data from the March 1990 sampling round onto Figure 18 demonstrates that much of the ground-water samples fall within the $Fe(OH)_3$ (iron hydroxide) stability field (Figure 20). Based on field Eh measurements (Table 3-7) and the presence of hydrogen sulfide, it is likely that redox conditions in the vicinity of the hide piles are sufficiently reducing to allow dissolved Fe(II) to migrate away from the area. When this water encounters a more oxidizing environment, $Fe(OH)_3$ precipitates, resulting in the removal of other metals by coprecipitation or adsorption.

3.5.1.4 Arsenic

The environmental geochemistry of As has been described extensively in several comprehensive literature reviews on a variety of topics, i.e., As speciation in the environment (Rai, *et al.*, 1984); the effect of microbiota on speciation (Cullen and Reimer, 1989); As metallurgy (Reddy, *et al.*, 1988); the effect of As on aquatic organisms (Phillips, 1990) and As toxicology (National Academy of Sciences, 1977).

Arsenic chemistry is complex due to occurrence of the semi-metal in two valence states (III) and (V), and because of organic complexes that form in a reducing environment, especially with As(III). Under oxidizing conditions, As(V) predominates (Figure 21), while under reducing conditions similar to those found in the vicinity of the hide piles, As(III) is the major form (Figure 22).

Precipitation/dissolution reactions of As in soils and ground waters have not been studied extensively. However, some stable inorganic precipitates form under environmental temperatures (298 K) and pressures (1 atm.), most notably $Ba_3(AsO_4)_2$ above pH 7 (Wagemann, 1978). In addition, precipitated iron arsenate, aluminum arsenate, and calcium arsenate have also been noted in river sediments (Chunguo and Zihui, 1988) while Hess and Blancher (1977) found that $Pb_3(AsO_4)_2$ and $Mn_3(AsO_4)_2$ controlled As solubility over a wide range of Eh and pH conditions in soils. Scorodite ($Fe(AsO_4) \cdot 2H_2O$) has been found to limit As solubility in acidic environments (Robins, *et al.*, 1988). However, it is unlikely that scorodite controls As solubility at the Site, because the ground-water pH (5.3 to 7.8) is too alkaline.

While precipitation of inorganic As species may be important in some specialized circumstances, it appears that As migration is dominated by sorption to inorganic (e.g. amorphous ferric hydroxide, manganese oxyhydroxides) surfaces (Rai, *et al.*, 1984). For example, Mok and Wai (1990) found a strong correlation between the extent of arsenic adsorption and the presence of free iron oxides and free manganese oxides in Coeur d'Alene river sediments.

A strong correlation was also found between As and Manganese (Mn) concentrations in the sediments of Puget Sound, leading to the conclusion that incorporation of As in the Mn oxide lattice was occurring (Peterson and Carpenter, 1986). Also, maxima in dissolved As and Fe occurred at the same depth in the sediment (beneath the dissolved Mn maxima), demonstrating that high dissolved As concentrations existed only under conditions favorable for the dissolution of both Fe and Mn oxides.

Belzile (1988) investigated the factors controlling As mobility in sediments from the Laurentian Trough where the Eh ranged from about +150 to -180 millivolts (mV), pH from 7.05 to 7.95, As from 1 to 30 mg/L, and FeS from 0 to 4,500 mg/L. He concluded that As was generally associated with Fe and Mn oxides because dissolution of Fe oxyhydroxide led to the simultaneous release of As and Fe into porewaters, supporting the hypothesis that As was sorbed to, or incorporated into, the solid matrix.

In summary, sorption of inorganic As(V) is controlled by the presence of Fe and Mn oxides and hydroxides. Several investigations (i.e., Leckie, *et al.*, 1980) have demonstrated that increasing sorbent concentrations (akin to increasing the surface sites available for adsorption) results in a greater percentage of the metal removed from solution (Figure 16).

In a reducing environment, such as in the presence of decomposing organic matter, arsenate is reduced to arsenite that may become methylated to monomethylarsonic acid (MMAA) or dimethylarsinic acid (DMAA). The following equations schematically describe the potential steps in the reaction pathway:

$$H_3AsO_4{}^\circ + 2H^+ + 2e^- \rightleftarrows H_3AsO_3{}^\circ + H_2O \qquad \text{(Eq. 5)}$$

$$CH_2O + 2H^+ + 2e^- \rightleftarrows CH_3OH \qquad \text{(Eq. 6)}$$

$$CH_3OH + H_3AsO_3{}^\circ \rightleftarrows CH_3AsO(OH)_2 + H_2O \qquad \text{(Eq. 7)}$$

$$CH_3AsO(OH)_2 + CH_3OH + 2H^+ + 2e^- \rightleftarrows (CH_3)_2AsO(OH) + 2H_2O \qquad \text{(Eq. 8)}$$
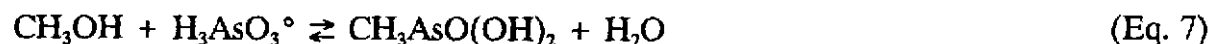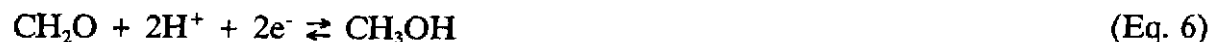
Eq. (5) describes the reduction of As(V) to As(III) in a reducing environment. Eq. (6) represents the breakdown of organic matter to generate methanol that subsequently forms MMAA (Eq. 7) and DMAA (Eq. 8), through bacterially mediated respiration (Figure 24). Under anaerobic conditions DMAA may be converted to arsine gas by the common soil bacteria *Pseudomonas* (McBride and Wolfe, 1971; Cheng and Focht, 1979).

Few studies have investigated the sorption of arsenate, arsenite, MMAA and DMAA. However, organoarsenical complexes are less tightly bound to soils (Wauchope, 1975; 1983). Specifically, the studies to date have found that in both aerobic (Mohan, *et al.*, 1982) and anaerobic environments (Holm, *et al.*, 1980), the order of affinity for sediment was arsenate >arsenite >MMAA >DMAA (Figure 25).

Arsenic Migration Rates

The As migration rates reported in the literature are typically based on research into application of arsenical pesticides on agricultural test plots. Consequently, these investigations are not representative of the complex geochemical environment present at the Site, and their results are not directly relevant. However, a brief review is included to provide baseline information against which As migration rates at the Site may be compared. In the simple systems reported in the literature, As tends to migrate slowly, probably because the more readily sorbed pentavalent form predominates in the typically aerobic, shallow, subsurface soils.

For example, Steevens *et al.* (1972) measured the migration rate of As applied over three years at 45 to 720 Kilograms/hectare (kg/ha) in a well-drained Plainfield sand containing

0.7 percent carbon, 4 percent silt, and 7 percent clay at a pH of 5.5. Arsenic moved into the subsoil to a depth of 38 centimeters (cm) for the 90 and 180 kg As/ha treatments and to a depth of 68 cm for the 720 kg As/ha, treatment.

Woolson and Isensee (1981) studied As migration rates of As over 5 years applied at 9.0, 17.9, and 89.6 kg As/ha on a Matapeake silt loam containing 1.5 percent organic carbon, 38.4 percent sand, 49.4 percent silt, and 1.2 percent clay at a pH of 5.1. Arsenic was found to have migrated down to 30 cm within three years of application of 89.6 kg As/ha, and to 30 cm within five years, for the 9.0 and 17.9 kg As/ha treatments.

Jackson and Levin (1979) reported the migration of As applied at 5.0 mg As/cm^2 in a Captina silt loam containing 63.7 percent clay, 29.1 percent silt, 7.2 percent sand, and 3.2 percent organic carbon at a pH of 5.6 and a cation exchange capacity (CEC) of 8.5 milliequivalents (meq)/100g. In this soil, As migrated to depths of 10 to 15 cm after one year.

In summary, As(V) sorbs more strongly to particle surfaces than the reduced forms. At the Site, it is possible that the migration of As downgradient from the West and East-Central Hide Piles has been facilitated by reduction of As(V) to As(III), which is subsequently methylated to form the more mobile MMAA or DMAA (Cullen and Reimer, 1989).

3.5.1.5 Chromium

Several monographs have been published that describe the environmental geochemistry of Cr (e.g., Schmidt, 1984; Rai, et al., 1988). In addition, a series of papers provide information concerning precipitation, oxidation and reduction reactions of Cr in soils, and the toxicity and effect of organic complexing on Cr mobility (Bartlett and Kimble, 1976a, 1976b; Bartlett and James, 1979; Ross, et al., 1981; James and Bartlett, 1983a, 1983b, 1983c). At surface conditions (T=298 K, p=1 atm.), Cr exists in two valence states, Cr(III) and Cr(VI). Generally, the more toxic and mobile Cr(VI) is found in oxidizing environments, while the less toxic and immobile trivalent form predominates in reducing environments (Figure 26).

Chromium (VI) is generally anionic and thus tends to be more mobile under alkaline conditions (pH > 7.5), although migration rates are highly dependent on the sorbent (Figure 27).

For example amorphous ferric hydroxide is extremely efficient at removing Cr(VI) from solution, while clays e.g., kaolinite and montmorillonite, are much less effective sorbents (Rai, *et al.*, 1988).

Chromium solubility is controlled by a limited suite of solid phases. The least soluble Cr(VI) precipitate is $PbCrO_4$, although $BaCrO_4$ has been shown to form rapidly under ambient environmental conditions. While the solubility product of $BaCrO_4$ is four orders of magnitude greater than $PbCrO_4$, it may act to limit Cr(VI) solubility in the vadose zone in the absence of Pb (Rai, *et al.*, 1988).

In a reducing environment and in the absence of Fe, Cr(III) precipitates readily to form $Cr(OH)_3$. However, due to the similarity in ionic radii (Cr = 1.25 Å, Fe = 1.24 Å), Cr can easily substitute for, or form solid solutions with Fe(III) in mineral structures (Faust and Aly, 1981), in which case the typical stoichiometry is $Cr_{0.25}Fe_{0.75}(OH)_3$ (Eary and Rai, 1988). In the absence of Fe, the ground-water pH-Eh conditions straddle the equilibrium line between $Cr(OH)_2^+$ and $Cr(OH)_{3(s)}$, suggesting that this precipitate controls Cr solubility in an Fe poor environment (Figure 28):

$$Cr(OH)_2^+ + H_2O \rightleftarrows Cr(OH)_{3(s)} + H^+ \qquad \text{(Eq. 9)}$$

in the presence of Fe, $Cr_{0.25}Fe_{0.75}(OH)_3$ may precipitate (Figures 29 and 30) by the reaction:

$$Cr(OH)_2^+ + 3Fe^{+3} + 10H_2O \rightleftarrows 4[Cr_{0.25}Fe_{0.75}(OH)_3] + 10H^+ \qquad \text{(Eq. 10)}$$

or

$$H_2O + Cr(OH)_2^+ + 3Fe(OH)_{3(s)} \rightleftarrows 4[Cr_{0.25}Fe_{0.75}(OH_3)] + H^+ \qquad \text{(Eq. 11)}$$
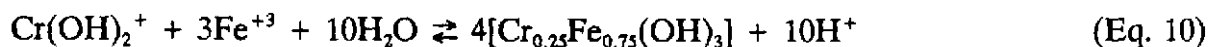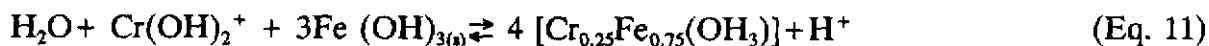
Under either scenario, Cr is present as Cr(III), based on the ground-water Eh-pH measurements, and on an evaluation of the aqueous Cr speciation data (Table 3-23).

Reactions 9 and 10 are well known to control Cr solubility. For example, precipitation of Cr(III) hydroxide and Cr(III)-Fe hydroxide minerals kept Cr(III) concentrations in ground water at levels below the drinking-water standard (50 μg/L) over a pH range of 5 to 10 (Rai and Zachara, 1986).

Grove and Ellis (1980a) reported that water-soluble Cr(III) and Cr(VI) converted to insoluble Cr(III) compounds in acidic Rubicon sand and Morley clay loam soils. They also reported similarities between Cr(III) and Fe(III) chemistries in these two soils. In addition, Grove and Ellis (1980b) reported that Cr(III) or Cr(VI) in soils can react with water-soluble iron to form a mixed hydrous Fe(III) and Cr(III) oxide mineral. Their findings are substantiated by Cary, et al. (1977), who reported that Cr soil chemistry appears to be dominated by formation of inert metal oxides of Cr(III) and Fe.

Iron in the reduced Fe(II) form has also been shown to rapidly facilitate reduction of Cr(VI) to Cr(III) that subsequently precipitates to form an insoluble hydroxide, i.e:

$$0.75Fe^{+2} + 0.25H_2CrO_4° + 2H_2O \rightleftarrows Cr_{0.25}Fe_{0.75}(OH)_3 + 1.5H^+ + e^- \qquad \text{(Eq. 12)}$$
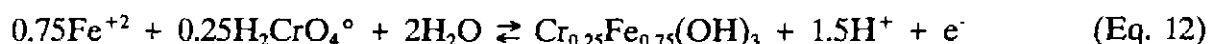
For example, Stollenwerk and Grove (1985) reported great difficulty removing Cr from a sand and gravel alluvial soil that had aged for 1.5 years. They found Cr(VI) underwent reactions that made it relatively insoluble. Chromium (VI) slowly became part of the structure of iron oxide, or was reduced to Cr(III) and coprecipitated with iron hydroxide. The source of electrons for reduction of Cr(VI) to Cr(III) probably included Fe(II) and organic matter.

Shroeder and Lee (1975) also found that Cr(VI) was reduced to Cr(III) by Fe(II) and dissolved sulfides, and that sand, bentonite, and iron oxide fixed and adsorbed 90 percent to 99 percent of the Cr(III) from the water phase in seven days. Their study demonstrated that Cr(III) sorbed and precipitated as a metal hydroxide under reducing conditions in sediments.

Bloomfield and Pruden (1980) reported that Cr(VI) was extensively reduced to Cr(III) in neutral pH soils under anaerobic conditions, while a rapid decrease of extractable Cr(VI) was observed by Ross, et al. (1982) during a three week soil incubation study, indicating rapid reduction of Cr(VI) in soil.

Although inorganic Cr geochemistry is well understood, only limited work has been undertaken to investigate organic complexing of Cr. Organic complexes are dependent upon the availability of organic ions. For example, an organic species that remains neutral across the pH range of the Site will not complex metals. Alternatively, an organic compound that loses hydrogen ions (H^+) will exist in an ionic form (as a conjugate base of that acid) and be able to complex positively charged metals (cations).

The tendency for dissociation of an organic species is defined quantitatively by the acid association constant (pKa). If the pH of the ground water is higher than this value, an organic compound loses hydrogen ions (H^+), allowing for complexation of metal cations. If the organic compound has more than one hydrogen ion in its structure, multiple pKa's may be associated with the analyte. Some of the organic acids that may control Cr(III) solubility at the Site have multiple pKa's. Compounds that complex Cr(III) are potentially present in soil organic matter at the Site (i.e., citric acid in hides; $pK_1 = 3.1$, $pK_2 = 4.8$, $pK_3 = 6.4$). In addition, aqueous organic complexes may be present as accessory chemicals used during hide processing (i.e., gallic acid; acid dissociation constant = 4.2, acid dissociation constant = 8.9); form during hide decomposition in the subsurface; or be present as a by-product from another chemical process (i.e., acetic acid; acid dissociation constant = 4.8). For example, James and Bartlett (1983b), investigating Cr behavior in tannery effluent, found that a soluble Cr(III)-citrate complex formed following the reduction of Cr(VI) to Cr(III). In the absence of citrate, no soluble organo-chromium complex was detected. By analogy, possible formation of a Cr(III)-acetate complex at the Site would explain the extent of Cr downgradient from the West and East-Central Hide Piles, where consideration of inorganic geochemistry alone would postulate rapid reduction and precipitation.

Chromium Migration Rates

As with As, the complexity of potentially competing organic and inorganic reactions at the Site precludes use of the published literature as an analog to predict the rate of Cr migration in the subsurface. The following references are provided to present baseline conditions, against which Cr mobility at the Site may be compared.

Banin *et al.* (1981) studied Cr(VI) migration rates in arid-zone surface soils containing 68 to 119 μg Cr/kg soil. After 28 years of irrigation at a rate of 7,000 to 8,000 cubic meters/ha/yr, chromium migration was confined within the top 40 cm of a loamy sand soil, a sandy loam soil, and a clay loam soil.

In other studies, Chang, *et al.* (1984) reported that Cr accumulated over a six year period in the zone of deposition in shallow Greenfield sandy loam and Domino loam; Degroot, *et al.* (1979) reported minimal Cr migration in fine sandy loam soils over a 30 year time period; while Hinesley, *et al.* (1972) reported that Cr migration was limited to a few centimeters beyond the zone of application.

Lund, *et al.* (1976) reported a maximum migration distance of about 3 meters for Cr in Hanford and Hesperia coarse-loamy soils and in Delhi sand and loamy sands over a 12 year period, while McGrath and Lane (1989) found that Cr had migrated only 3.5 cm below the plow layer, 47 years after its addition to soil as part of sewage sludge.

In summary, if Cr was initially released in the hexavalent form at the Site, it is likely that the presence of Fe(II) and the generally reducing environment in the hide pile areas resulted in the reduction of Cr(VI) to Cr(III) and subsequent precipitation as a hydroxide. However, if organic acid activities are at the millimolar levels, complexing of Cr(III) by organic acids is likely to maintain Cr in solution (James and Bartlett, 1983), and may explain the extent of the Cr ground-water plume downgradient of the hide piles.

3.5.1.6 Mercury

Mercury (Hg) exists in a large number of different physical and chemical forms, each of which may have widely disparate transport and toxicity characteristics. As a result there have been several reviews describing various aspects of Hg chemistry (i.e., Gavis and Ferguson, 1972; Jernelov, et al, 1975; Williams and Funston, 1987; Robertson, *et al.*, 1987; Kabata-Pendias and Pendias, 1984). The principal inorganic forms include complexation by Cl under mildly acidic, oxidizing conditions and by sulfur under the reducing conditions characteristic of the Site (Figure 31). However, these compounds are extremely insoluble, i.e., 0.2 ng/L in equilibrium with HgS between pH 5 and pH 7.

Of particular interest is the superimposition of ground-water conditions (as determined during the GSIP) on the Hg Eh-pH plot (Figure 32), which shows that much of the Hg occurs in the elemental state at a maximum solubility of about 60 μg/L at 25°C. In addition, the generally reducing environment in the ground-water system precludes formation of several aqueous oxidized species, most notably, Hg_2^{+2}, $HgCl_2°$ and $Hg(OH)_2°$ (Figure 31). However, Hg tends not to form precipitates except for coprecipitation of Hg(II) with $Fe(OH)_3$ (Inoue and Munemori, 1979). While this reaction may occur in surficial soils, it is unlikely in ground water except in specific wells (i.e., OW-16) where Eh-pH conditions are conducive to Fe precipitation (Figure 17).

The chemistry of Hg is especially complicated by its affinity for organic groups, in particular - CH_3, $-NH_2$ and -SH. These organic species may be important constituents of the aqueous assemblage at the Site, although Faust and Aly (1981) conclude that between a pH of 5 to 9 and at redox conditions below 500 mV, organic Hg complexes tend to be thermodynamically unstable. These conditions are typical of those at the Site. Consequently, methylation of the Hg is likely to be unstable, allowing for the sorption of Hg to $Fe(OH)_3$ and other surfaces.

For example, there is a body of information demonstrating that Hg sorption is controlled primarily by the fraction of organic carbon, and by the availability of manganese oxide surfaces in soils, aquifers and sediments. Generally, in the absence of Cl, Hg is readily sorbed by many materials under oxidizing conditions, essentially independent of pH over the range 5 to 8 (Bruninx, 1975; Kinniburgh and Jackson, 1978; Inoue and Munemori, 1979). Attenuation of Hg, probably as the $Hg(OH)_2°$ complex in surficial soils by oxide surfaces, is cited to explain the concentrations detected at the Site (2 μg/L to 5.7 μg/L).

Sorption of Hg on soils has been demonstrated in several studies. For example, Hogg *et al.* (1978) investigated the sorption of Hg in Asaquith sand containing 7 to 13 mg/kg Hg and in Oxbow loam containing 22 to 37 mg/kg Hg. Nineteen weeks after applying 10 mg/kg Hg as $HgCl_2$, phenylmercuric acetate, and methylmercuric chloride, more than 99.7 percent of the Hg could not be extracted by several extractants, indicating that the Hg was immobilized by soil colloids.

Elsokkary (1982) found that Hg deposited on soil from industrial emissions over several decades had migrated to a maximum depth of only 40 cm in a clay loam soil. These soils possessed a pH range from 7.5 to 8.1, organic matter contents from 1.6 to 2.8 percent, and 2 to 4 percent carbonate. The total Hg content of the soils ranged from 10 to 495 μg/kg.

William, et al. (1980) studied Hg migration rates on a Dublin loam with a pH range of 5.2 to 5.6. Sludge treatments were applied from 0 to 225 tons/ha containing a Hg concentration between 5 and 14 mg/kg. The sludge was incorporated into the upper 20 cm and after three years the soil was analyzed to a depth of 80 cm to determine Hg migration. At sludge applications of 225 tons/ha, Hg had percolated to a maximum depth of only 5 cm, while migration of 1 to 2 cm was more common for sludge applications between 45 and 135 tons/ha.

In summary, an analysis of published migration studies demonstrates that Hg exhibits low mobility in soils similar to those at the Site, and low solubility in the event Hg percolates to ground water.

3.5.1.7 Lead

The geochemical factors controlling lead (Pb) concentrations and mobility in both stream and ground waters are well known (Hem, 1975, Saether, et al., 1988). In ground waters, Pb exists primarily as Pb(II), in which form the cation is subject to complexation, sorption and precipitation reactions controlling the dissolved Pb concentration.

The important precipitates in soils include anglesite ($PbSO_4$), cerrusite ($PbCO_3$), $Pb_3(PO_4)_2$ and $Pb(OH)_2$, depending on the pH and the activity (concentration) of the anions. For example, Santillan-Medrano and Jurinak (1975) conducted equilibrium batch studies of solid phase formation of lead in soils. They reported that in noncalcareous soils, Pb was regulated by Pb hydroxide and phosphates. In calcareous soils at alkaline pH, Pb solubility was controlled by $PbCO_{3(s)}$.

A representative Eh-pH diagram for the system Pb-H2O-CO3-SO$_4$ using analyte activities determined from geochemical modeling of well OW-14, demonstrates that at the Eh-pH conditions characteristic of the Site, Pb is not likely to precipitate. Rather, Pb will be complexed as $PbSO_4^\circ$ and Pb(OH)+, below and above pH 6.6, respectively (Figure 33).

Superimposing the measured Eh-pH conditions on the diagram (Figure 34) demonstrates that $PbSO_4^\circ$ will control Pb solubility in a majority of the wells. In areas of lower SO_4 concentrations, the dominant form will be Pb^{+2}.

In addition to attenuation by precipitates, Pb readily sorbs to alumina, silica and $Fe(OH)_3$ surfaces. Hildebrand and Blum (1975) found that clay minerals, amorphous iron hydroxides, goethite, hematite, and organic matter all adsorbed Pb, while Kinniburgh, et al. (1976) established that Pb was selectively sorbed at low pH (Figure 35). Zimdahl and Skogerbee (1977) in a study of 18 soils containing 1.9 to 33 mg/L Pb with a pH between 5.3 to 8.1, found that the soils had a large capacity to attenuate Pb by complexation with organic matter, precipitation as carbonates, and sorption by iron and manganese oxides.

Published Lead Migration Rates

Transport rates for lead reported in the literature must be related to the specific chemical forms of lead (source dependant) and soil characteristics before applying these estimates to the Site. Possible lead sources at the Site include releases of lead arsenate pesticides formulated during the period from 1892 to 1920, Pb from the dissolution of spent pyrite, Pb from possible spills of leaded gasoline, and Pb from dye wastes. Lead released from each source is associated with a characteristic suite of companion analytes or Pb complexes. For example, the signature for leaded gasoline includes toluene, xylene, and possibly benzene, if the spill is recent (early 1970's); pyrite Pb would be associated with sulfide and sulfate complexes, while Pb pesticides may result in Pb arsenate aqueous complexes in ground water near the source.

The variety of Pb sources at the Site are sufficiently dissimilar to the published Pb transport rates as to render the literature data of limited use. However, a few studies representative of the large body of literature on this subject are included to provide baseline conditions from which comparisons to Site conditions may be made.

Generally, Pb is extremely immobile. For example, Banin et al. (1981) studied the migration rates of lead in arid-zone surface soils containing 0.73 to 18 mg/kg. After 28 years of irrigation

at a rate of 7,000 to 8,000 cubic meters/ha/yr, lead migration was confined within the top 40 cm of a loamy sand soil, within the top 20 cm of a sandy loam soil, and within the top 20 cm of a clay loam soil.

Page and Ganje (1970) estimated Pb migration rates in ten Southern California alluvial surface soils with pHs from 5.4 to 7.4 and from 12 to 52 mg/kg lead. Lead migration was limited to the surface 2.5 cm over a 27 to 49 year time period.

McGrath and Lane (1989) investigated Pb migration at the Woburn, England Experimental Farm, 47 years after its addition to soil as part of sewage sludge. They found that Pb had migrated only 3.5 cm below the plow layer. The total Pb content of this soil ranged from 10.4 to 102 mg/kg. Another evaluation of sludge derived lead (Williams *et al.*, 1980) indicated that Pb movement was limited to a maximum of 5 cm in Dublin loam soil. The retardation of Pb in these studies is notable because organically complexed metals are more mobile in soil when applied as sludge, than when applied in the inorganic form (Gerritse *et al.* 1982; O'Conner, *et al.*, 1983).

Based upon the above published data, Pb migrates extremely slowly (e.g. cm/yr.) through unsaturated soils. The Pb concentrations detected during the GSIP RI program support the conclusions presented in the literature. For example, Pb was only detected in one dissolved ground-water sample at a concentration of 16 μg/L. In addition, only two ground-water samples, OW-14 (299 μg/L) and OW-28 (162 μg/L), contained total Pb concentrations greater than 50 μg/L. It is also noteworthy that the dissolved Pb concentrations in these wells were 16 μg/L and <2μg/L respectively, while the Fe concentrations in these wells (21.6 and 226 mg/L, respectively) were among the highest at the Site. These data suggest that $Fe(OH)_3$ precipitated in the observation wells adsorbed Pb to the amorphous soils, hence the absence of concentrations greater than 50 μg/L in the samples analyzed for dissolved metals.

3.5.1.8 Alkalinity and Anionic Constituents

Over the pH range of ground waters at the Site, bicarbonate (HCO_3^-) is the predominant form of inorganic carbonate alkalinity. The major source of HCO_3^- is atmospheric CO_2 entrained in the aquifer, replenished and maintained at an equilibrium activity by calcite in the overburden. In addition to inorganic carbon, it is likely that organic acids also contribute

to the total alkalinity. This hypothesis is supported by historical activities at the Site, such as the existence of an acetic acid manufacturing facility, and by the presence of a large source of organic material in the form of the hide piles. Analysis for alkalinity involves titrating the solution to pH 4.5. Consequently, any acetic or other organic acids (principally carboxylic acids), with a pKa between the ambient ground-water pH and pH 4.5 (the end point of the titration) will contribute to the titrated alkalinity (Figure 36). The most important effect of these acids is the strong aqueous complexes they form with cationic metals (e.g., Cr, Pb, Hg, etc.).

A plume of chloride originates from the East-Central Hide Pile, probably due to the leaching of salts used in the tanning process from the hides. Contribution of Cl from pre-1933 era HCl production is unlikely, given the well defined nature of the plume emanating from the hide pile that extends approximately 6,000 feet between wells OW-16 and OW-20. Because Cl is a conservative (i.e., non-reactive) solute, it serves as a good tracer for determining ground-water flow velocity. Assuming an average ground-water flow rate of approximately 1.62 ft/day (based on a range of 0.99 ft/day to 2.26 ft/day; Section 3.2.2.6), the travel time for Cl should be approximately ten years, in excellent agreement with the burial date of the East-Central Hide Pile (circa 1980).

Sulfate in the aquifer results from dissolution and oxidation of spent pyrite from the sulfuric acid manufacturing era (pre 1933). It is biologically important and may act as an electron acceptor in the absence of oxygen. The absence of SO_4 in ground-water samples collected from OW-16 is evidence that the reducing conditions under the East-Central Hide Pile facilitate reduction of SO_4 leached from the pile to H_2S. This observation would explain generation of $H_2S°$ from the hide piles (i.e., up to 20,000 ppb in soil gas) (Roux Associates, Inc., 1984). The highest SO_4 concentrations are found west of the East-Central Hide pile, indicating that the East Hide Pile or the West Hide Pile may also be contributing to the SO_4 plume. In addition to the consumption of sulfate by microbially facilitated reactions, SO_4 solubility may also be controlled by precipitation of gypsum ($CaSO_4 \cdot 2H_2O$), through dissolution of calcite ($CaCO_3$) in the overburden by mildly acidic, sulfate-rich ground water, i.e.:

$$2H_2O + H_2SO_4 + CaCO_{3(s)} \rightleftarrows CaSO_4 \cdot 2H_2O_{(s)} + H_2CO_3 \qquad \text{(Eq. 13)}$$

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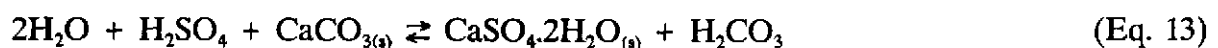
Sulfate is also well known to compete for sorption sites with chromate. For example, Leckie, *et al.* (1980) demonstrated that as SO_4 concentrations increased from 10 to 10,000 mg/L, adsorption of CrO_4^{-2} by $Fe(OH)_{3(am)}$ at pH 6 decreased from 90 percent to 40 percent. By analogy, it is likely that the presence of SO_4 in the vadose zone at the Site facilitates Cr migration through competitive exclusion on the available surface sites.

Phosphorous (P) was detected downgradient of the East-Central Hide Pile. Phosphate is an important analyte in biological reactions as a limiting nutrient controlling microbial population growth rates. In addition, PO_4 is chemically similar to arsenate (AsO_4) and may influence As mobility. For example, even though PO_4 is less strongly adsorbed than AsO_4 (Wauchope and McDowell, 1984), it may increase arsenate mobility through competition for the same adsorption sites (Goldberg, 1986).

3.5.1.9 Statistical Analysis/Geochemical Modeling

Summary statistics for Phase 2 soils data from different depths in the soil profile were calculated for the log-normally transformed data base to determine the geometric mean metal concentrations for As, Cu, Cr, Hg, Pb and Zn. These values were then compared with average soil metal concentrations derived from acidic rocks (gneiss) characteristic of the Site petrology (Kabata-Pendias and Pendias, 1984).

To evaluate the relationships between transport mechanisms and the available data, statistical relationships were examined for the 1990 dissolved ground-water data set (n = 22), omitting Ag, Hg and Cr due to insufficient data points (0, 0, and 4 respectively).

The ground-water data were also evaluated using Piper diagrams in an attempt to distinguish between ground waters of different source and/or composition, and to evaluate potential mixing of ground waters. Finally, the equilibrium geochemical model MINTEQA2 (Brown and Allison, 1987), was used to determine potential metal solubility controls that result from precipitation of solids in the aquifer. The variables incorporated in these analyses included pH, Eh, alkalinity, Al, As, Ba, Cd, Ca, Cr, Co, COD, Cu, Fe, potassium (K), Mg, Mn, sodium

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(Na), nickel (Ni), PO_4, selenium (Se), Sn, SO_4, Total Organic Carbon (TOC), Total Suspended Solids (TSS), vanadium (V), and Zn. Mercury and Ag were omitted from the list of variables because their concentrations were below the analytical detection limit during this sampling round.

Summary statistics were calculated for soils metal data using three data bases (I, II and III). Data base I represented 1045 cases collected during the 1983 RI, while data bases II and III utilized combined PDI, GSIP and RI data. Data base I contained As, Cu, Cr, Pb, Hg and Zn, data base II (131 cases) represented soils designated as being collected from hide areas, while data base III (1571 cases) represented soils collected from non-hide soils respectively. The combined data base was segregated into hide and non-hide unimpacted soils samples to determine if the two soil populations are statistically different.

Geometric mean concentrations and standard deviations were determined for a log-normally transformed data base, developed after inspection of the histograms demonstrated that the raw data were positively skewed (e.g. Figure 37). This transformation is commonly used to generate a normally distributed data base amenable to multivariate statistical analysis (Davis, 1986). After data analysis, average metals concentrations at the Site were determined by taking the exponent of the average concentration of the transformed variable (Table 3-24).

Based on this statistical analysis, the average Pb and Hg concentration in data base I soils was approximately one order of magnitude greater than the upper range of values reported for soils from U.S. gneisses (the Site overlies gnessis crystalline bedrock). The average As soil concentration is 5 times, Cr 2 times, whereas Cu and Zn are similar to the U.S. average (Table 3-25).

A conventional correlation statistic (Davis, 1986) was also calculated after standardizing the transformed data set to remove numerical bias. This was achieved by subtracting the mean concentration from each record and dividing by the standard deviation. A pairwise test (Walpole and Myers, 1985) was selected to maximize the number of samples included in the

correlation matrix. The results (Table 3-26) demonstrate that there is a strong correlation (at the 1 percent level) between As, Pb, Hg and Zn, but the Cr is not correlated with As, Pb, or Hg, and only weakly with Cu and Zn. These data suggest that the source of Cr (the hide piles) is spatially distinct from the source of As, Cu, Hg, Pb and Zn (inferred to be pesticide residues, dye wastes, spent pyrite, etc.)

To further investigate the hypothesis that the hide and non-hide soils are representative of statistically different populations a Student's t-test was performed to compare the distribution of As, Cr and Pb concentrations in the hide and non-hide soil data bases (II and III) assuming that the population was collected randomly, the populations are normally distributed (data lognormally transformed to meet with criteria), and the variances are approximately equal, verified using Bartlett's test (Walpole and Myers, 1985) for equality of variances (Table 3-27). Parametric methods such as the Student's t-test are robust to departures from normality, particularly when larger sample sizes (i.e. > 30) are available (OSWER, 1986).

The results of this analysis (Table 3-27) demonstrate that the means of the two soil populations are different (at the 5 percent level) for As, Cr and Pb, suggesting that the hide and non-hide soils are statistically distinct in terms of metals concentrations.

Statistical Analysis of Ground-Water Data

Based on probability density function plots, the frequency distribution of many of the variables in the GSIP ground-water data set (dissolved constituents) were found to be positively skewed. Therefore these populations were logarithmically transformed to convert the data set into a normal distribution (Figures 37 and 38). The entire data set was then standardized (converted to mean = 0, standard deviation = 1) to prevent numerical bias, and the Pearson statistic used to calculate correlation coefficients.

The transformed, standardized data base was used to evaluate spatial similarities between ground-water chemistry using hierarchical cluster analysis. The objective of this test was to determine if ground waters from different areas at the Site could be grouped quantitatively, in conjunction with the more qualitative Piper diagram to test the statistical relationship

between the major cations (Ca, K, Mg, and Na) and anions (Cl, HCO_3 and SO_4) in Site ground waters. A trilinear diagram, (Piper, 1944) is often used to draw inferences pertaining to groupings of waters at a site. The plot is also useful in distinguishing the evolution of ground waters, if waters of differing chemical composition mix resulting in a commingled water with a different aqueous chemistry.

Each of the 22 wells sampled during the GSIP program were put into one of four groups that were identified by calculating complete linkage Euclidean distances (Figure 39). Superimposing the four groups upon the Piper diagram (Figure 40), demonstrates that not only are the ground waters sampled by the observation wells not spatially related, but that sophisticated statistical techniques cannot deconvolute any underlying relationship between ground-water chemistry in the wells. This conclusion is based upon the absence of any trend in major anion and cation chemistry downgradient from the implied sources of contamination. Only one relationship is apparent, namely the grouping of wells OW-4, OW-6, OW-7, OW-10 and OW-15, all of which are interpreted as "background" wells. The remaining well chemistries are widely spread across the diagram, possibly representing a variety of different sources, each of which contribute characteristic analytes to each well.

While statistical comparison between wells did not identify strong correlations between aqueous parameters, the Pearson statistic did identify some geochemical relationships between individual analytes (Table 3-27). For example, pH and Eh were inversely correlated (r = -0.78) at the 1 percent level (where r > 0.53 is significant at the 1 percent level when n-1 = 21; Snedecor, 1956). This interpretation supports the conclusion that redox reactions are occurring across the Site. Specifically, the slope of the Eh-pH relationship (Figure 41) is similar to the lines on the Eh-pH diagrams corresponding to Cr(III) and Fe(III) aqueous species in equilibrium with $Cr_{0.25}Fe_{0.75}(OH)_3$ (Figure 23) and Fe(II) in equilibrium with $Fe(OH)_3$ (Figure 13).

Statistically significant relationships are also apparent between Cu and Zn (r = 0.60), between Cu and pH (r = -0.59), and between Zn and pH (r = -0.62). The negative correlations with pH demonstrate that as the pH increases, dissolved Cu and Zn decrease, probably due to increased sorption to available substrates, such as clays or amorphous hydroxides. The inverse correlation between divalent cations and pH represents a quasi-sorption curve (Figure 42).

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In addition, pH is positively correlated with As (Figure 42), suggesting that As mobility (in the form of dissolved concentrations) increases with pH, consistent with the findings of other workers (e.g., Gulens, *et al.*, 1979; Pierce and Moore, 1980).

Other important correlations include alkalinity with COD ($r = 0.81$), suggesting that conjugate organic acids (e.g., acetate) contribute to the measured inorganic alkalinity; As with Fe ($r = 0.62$), implying formation of an $FeAsO_4°$ complex in some locations; Ca with alkalinity ($r = 0.44$, significant at the 5 percent level $\{r = 0.41$ when n-1 $= 21\}$), implying possible calcium carbonate complexing/precipitation; As with PO_4 ($r = 0.62$) suggesting that these two elements migrate at similar rates, consistent with the observations of this and other investigations; and As with COD ($r = 0.76$), suggesting that As concentrations in the vicinity of a source are primarily organically bound, resulting in an increased oxygen demand to degrade the complex (Figure 41).

Geochemical Modeling

Chemical analyses from selected well locations representing an approximately north-south transect across the Site through the East-Central Hide Pile (Figure 44) were used as input to the computer model MINTEQA2, an updated version of MINTEQA1 (Brown and Allison, 1987), originally coded as MINTEQ by Felmy, *et al.*, (1984). MINTEQA2 is an equilibrium mass-balance geochemical model used to calculate the elemental aqueous speciation, and the stability of solid phases with respect to the dissolved constituents. The model is useful in evaluating different solubility controls on metal transport at the Site.

MINTEQA2 performs speciation calculations by simultaneously solving equations that represent formation of ion pairs, complex ions, and solids, using an extensive data base of internally consistent values that includes most complexes and solids for which thermodynamic data are reported in the literature. The potential for mineral precipitation or dissolution is assessed using the saturation index (SI) which is based on the relationship between analyte activities (the ion activity product, IAP) and the thermodynamic calculation of the solubility product (Ksp). The SI of a mineral is determined using the equation:

$$SI = \log_{10} \frac{[IAP]}{[K_{sp}]} \qquad \qquad \text{(Eq. 14)}$$

If the SI is greater than zero, the solution is theoretically oversaturated with respect to the solid, and may precipitate. If the SI is less than zero, the solid is undersaturated with respect to the solution, and, if present in the system, will dissolve. At SI = 0, the solid and solution are in equilibrium, and neither dissolution nor precipitation reactions are predicted to occur.

Not all solids with an SI greater than zero can be realistically expected to precipitate from every system. Some solids are known to occur only in high pressure and/or high temperature environments and should not be considered in systems where near-surface conditions exist. Solid phases that may control metal solubilities at the Site include calcite, gypsum, barite, $Ba_3(AsO)_4$, and hydroxides of Cr and Fe.

In the absence of Site specific $CO_{2(g)}$ data, the partial pressure of $CO_{2(g)}$ was fixed at atmospheric levels. All dissolved Fe was entered as Fe(II), likely to be the principal form in the reduced ground waters. The pH and Eh were entered as measured in the field at the Site.

Speciated charge imbalances ranged from +20 percent to -80 percent and calculated ionic strengths between 0.005-0.1 m. The worst charge imbalances (i.e., greater than 15 percent) were associated with the higher ionic strength solutions that are typically more difficult to analyze due to matrix interferences.

The results of the simulations (Table 3-28) demonstrate that the potential metal solubility controlling solids are all undersaturated with respect to ground water in upgradient well OW-21, indicating that these solids are not precipitating from solution in this area of the aquifer. However, as ground water mixes with hide pile leachates (represented by well OW-16), $Ba_3(AsO_4)_2$, $FeO \cdot OH$, calcite, siderite ($FeCO_3$), $Cr(OH)_3$, and $Cr_{0.25}Fe_{0.75}(OH)_3$ all become oversaturated with respect to ground water, and potentially may precipitate from solution (Figures 44 and 45). All the minerals (with the exception of gypsum and barite ($BaSO_4$) attain maximum oversaturation in this well. As analytes precipitate from, and are diluted by, downgradient ground water, the SIs decrease, until in the most downgradient well (OW-7),

only $FeO \cdot OH$ remains oversaturated. Gypsum and barite are undersaturated in well OW-16, probably because all the sulfur is in the form of sulfide rather than sulfate. Downgradient from the hide pile (OW-12), oxidation of sulfide to sulfate allows potential precipitation of gypsum and barite.

3.5.2 Measurement of the Critical Parameters Controlling Arsenic, Chromium, Lead and Mercury

The critical parameters which control the mobility of arsenic, chromium, lead, and mercury in the ground water at the Site were measured during the ground-water investigation. These parameters were identified in the GSIP Work Plan based upon an evaluation of the available literature and existing RI/FS data base. These parameters included:

- grain size analysis;
- Eh;
- pH;
- TOC;
- Fe Oxide;
- Mn Oxide; and
- Total Carbonate.

Soil samples were collected during the installation of the GSIP observation wells. Split spoon soil samples were collected 5 to 7 feet below land surface (unsaturated zone) and within the screened zone. Field measurements of several of these parameters are provided in Table 3-2 and the analysis of As, Cr, Pb, Hg, TOC, Fe oxide, Mn oxide and total carbonate are provided in Appendix C.

In addition, the field conditions that may control the mobility of these metals in ground water were measured. Water levels were measured on several occasions to characterize the extremes of annual surface-water and ground-water conditions (seasonal high levels and seasonal low levels). These water level data were discussed in detail in Section 3.2 "Ground-Water Investigation". The influence of seasonal changes in ground-water levels and flow directions on the extent of inorganic and organic compounds in ground-water was also discussed in Section 3.2.

The relationship of these parameters to the concentrations of As, Cr, Pb, and Hg in the ground water was discussed in Section 3.5.1 "Evaluation of Literature and Database". An evaluation of the influence of these parameters on current and future mobility is discussed in Section 3.5.4 "Evaluation of Current and Future Mobility".

3.5.3 Determination of the Chemical Species of Arsenic, Chromium, Lead, and Mercury

The chemical forms of As, Cr, Pb, and Hg in ground water, surface water, and stream sediments were determined according to the procedures outlined in the GSIP Work Plan by Radian and ERCO. The results of these analyses are provided in Appendix C.

Although the results of the validation of the speciation data indicate that the data is quantitative or qualitative (Appendix D), according to USEPA Region 1 data validation criteria, the validity of the speciation data is questionable because the holding times for the arsenic (III) and arsenic (V) analyses were between 14 and 30 days resulting in the possible adsorption of arsenic to precipitated $Fe(OH)_3$ (Pierce and Moore, 1982; Robins, 1988). The subsequent centrifuging of the samples may have resulted in the removal of $Fe(OH)_3$ along with sorbed/coprecipitated metals such as As and Cr.

Moreover, the $Fe(OH)_3$ data are questionable because the holding times for this analysis exceeded 80 days and the reaction of $Fe(II)$ to $Fe(III)$ occurs rapidly (within minutes). This, coupled with the centrifuging of the samples, may have resulted in loss of analytical accuracy.

The critical ground-water data met all QA/QC criteria and have been used to meet the objectives of the metals mobility study even though the metals speciation data is considered questionable. The ground-water data was important in developing an understanding of the geochemical parameters that control the mobility of As, Cr, Pb, and Hg in ground water. This understanding was used, in turn, to formulate a paradigm (concept) to explain the geochemical processes present within the Study Area. The development of this paradigm, in turn, identified additional data needs required to test it. These data needs are discussed in Section 5.2.1.

3.5.4 Evaluation of Current and Future Mobility

The objective of this section is to combine the theory of metal transport described in previous sections with Site data, in order to develop a hypothesis that describes the migration of As, Cr, Pb, and Hg in each media at the Site. The paradigm developed for the Study Area will be used as a basis from which to predict future contaminant migration patterns, and to evaluate specific remedial alternatives.

In developing the paradigm, it was assumed, based upon the data developed during the PDI and GSIP, that ground water traverses the Site at an average of approximately 1.62 ft/day, that the East-Central Hide Pile intersects the ground-water table, that the depth to ground water is shallow (e.g., about 10 feet below the surface), and that precipitation exceeds evapotranspiration, resulting in a net recharge to the aquifer.

Under reducing conditions, infiltration of precipitation through the soils containing metals at a hide pile leaches metals, the mobility of which is influenced through complexing with organic conjugate bases released from the hide piles. The East-Central Hide Pile contributes Cl, Cr, PO_4, SO_4 and dissolved organic carbon to the ground water. The reducing and anoxic environment at the hide piles (Figures 46 and 47), reflected in the high chemical oxygen demand (Figure 48), is due to the microbial degradation of organic material within the hides that eventually give rise to a TOC ground-water plume (Figure 49). The reducing conditions generated by the hide piles are conducive to the mobilization of As from contaminated soils intersected by the plume emanating from the hide piles. It is important to note that As mobility is only facilitated downgradient from the hide piles. In other areas of the Site where conditions are more oxidizing, concentrations of As are less than 50 μg/L.

The ground-water conditions below the East, West, and East-Central Hide Pile are strongly reducing, while conditions over the rest of the Site are relatively oxidizing. The reducing zone is located in the ground-water plume extending downgradient from the piles, particularly from the East-Central Hide Pile and is characterized by Eh < 0 mV and dissolved oxygen < 1 mg/L. In contrast, oxidizing conditions exist across the remainder of the Site, with Eh potentials above zero (Figure 46), dissolved oxygen above 1 mg/L (Figure 47), and the COD below 25 mg/L (Figure 48). As ground water flows from reducing to oxidizing zones, geochemical reactions occur which affect the mobility of dissolved metals.

The presence of volatile reduced sulfur compounds directly beneath the hide piles is clearly representative of anaerobic, reducing conditions. For example, in the East Hide Pile, H_2S and CH_3HS gas were measured at up to 21,000 mg/L and 400 mg/L, respectively, with 250 mg/L H_2S in the West Pile and an unmeasured sulfide odor in the East-Central and South Hide Piles (Roux Associates, Inc., 1984). The high sulfide concentrations in the East Hide Pile may be due to the water table mound limiting O_2 transfer.

Breakdown of the hides is likely to have resulted in generation of organic acids, based on the extremely high alkalinities measured in Observation Well OW-16. Ground water intersecting the East-Central Hide Pile has been affected by these conditions. The maximum extent of the downgradient plume may be estimated by evaluation of Cl, emanating from the hide piles, that acts as a conservative tracer (Figure 50) and appears to have migrated as far downgradient as OW-2. In addition to the hide piles, another likely source of alkalinity is the landfill to the northwest of the Site (Figure 51) because landfill leachates commonly generate alkalinity in the form of organic acids (Baedecker and Back, 1979). The possible presence of dissolved organic acids is important, because they form strong aqueous complexes with metal cations, increasing metal solubility and mobility. In addition, dissolved organic carbon may act as a source of nutrients for bacteria in the aquifer, necessary for the biologically induced methylation of As compounds (Rai, *et al.*, 1984).

Additional evidence for the presence of organic acids includes the correlation between alkalinity and COD ($r = 0.81$) and the elevated TOC concentrations. For example, well OW-16, located on the southeast edge of the East-Central Hide Pile, reflects a source of alkalinity present in the hide pile (11,000 mg/L as $CaCO_3$), TOC (2,770 mg/L), and COD (1,350 mg/L).

In general, arsenic pesticide residues are not colocated with the hide piles, based on the lack of correlation between Cr and other metals (As, Pb and Hg) analyzed in Phase 2 soils (Table 3-28). However, Pb and Zn arsenic pesticide residues are an important source of these metals, based on the correlation between As and both Pb and Zn in the soils ($r = 0.72$, $n = 596$, and $r = 0.54$, $n = 819$, respectively). These data are consistent with the paradigm because As is only mobilized in areas downgradient of the hide piles so co-location of As and Cr is not a criteria for As mobility.

Infiltration of precipitation in the reducing conditions in the vicinity of the hide piles results in the dissolution of arsenate and arsenite salts and percolation of As(V) and As(III) through the vadose zone to the shallow water table where the reducing environment, coupled with the presence of methyl groups from hide breakdown results in reduction of any As(V) to As(III), and subsequent methylation to form mobile MMAA and DMAA (Figure 52).

Transport of As in the aquifer is also enhanced by the presence of PO_4 (Figure 53) that competes for surface sites on Fe oxides (Hingston, *et al.*, 1971) and soils (Livesey and Huang, 1981; Barrow, 1974b). As mobility is largely unaffected by the presence of SO_4 distributed extensively in ground water at the Site (Figure 54) or by Cl (Figure 50) (Livesey and Huang, 1981; Leckie, *et al.*, 1980).

Based upon the Cr ground-water speciation data, the anoxic conditions also result in reduction of remnant Cr(VI) to Cr(III) which should coprecipitate with Fe to form the sparingly soluble $Cr_{0.25}Fe_{0.75}(OH)_3$ or, in the absence of Fe, as $Cr(OH)_3$. Once reduced, Cr(III) is unlikely to be re-oxidized to Cr(VI), even in the presence of oxygen, due to kinetic limitations (Bartlett and Kimble, 1976). The hydroxide also provides a source of surface sites for sorption of metal cations, following the selectivity sequence Cr(III) > Pb > Cu > Zn > Cd > Mg (Kinniburgh, *et al.*, 1976; Leckie, *et al.*, 1980). However, despite potential precipitation, Cr is migrating in ground water (Figure 55) because the Cl:Cr ratio is 0.24 in both wells OW-16 and OW-12, suggesting that there is negligible attenuation of Cr over this distance. The migration of Cr is possibly due to organic complexation by organic conjugate base, possibly acetate, which, due to its anionic form at the ambient ground-water pH (typically 6-7.5, Figure 56), will readily complex metal cations. The general absence of Pb in ground water is probably due to selective sorption in the vadose zone (Figure 57).

Upon recharging to surface water (e.g., the Hall's Brook Holding Area) metals are filtered from ground water by sorption to sediment, resulting in decreased concentrations in surface waters. Because of biological activity, a large reservoir of organic carbon is likely to be present, (e.g. TOC concentrations in the sediments were above 20 percent in samples SW-9 and SW-16) to which neutral organic complexes (DMAA, Cr-acetate, etc.) may sorb.

Consequently, the reducing environment in this portion of the Study Area is likely to remove metals from solution in a manner analogous to that demonstrated to effectively retain metals from acid mine drainage (Wildeman and Laudon, 1989) and coal mine effluents (Girts and Kleinmann, 1986).

4.0 RISK ASSESSMENT

The purpose of this risk assessment was to determine the extent to which ground-water and surface-water conditions, as delineated during the GSIP RI and the PDI, may affect human health or the environment. Results of this assessment are presented in the sections which follow.

4.1 Background

The Industri-Plex Superfund Site is located on a 244-acre parcel of land located in northeast Woburn, Massachusetts. Since 1853, chemical companies have used the Site for the processing of raw materials and manufacture of chemicals for use in the leather, textile, and paper industries. Wastes and by-products from these activities, primarily metal salts and processed animal hides, were deposited in selected locations near these industries. Activities associated with an attempt to develop the land dispersed much of the waste material into wetland areas.

Although many investigations have been performed at the Site, only the more recent have addressed impacts to public health or environmental receptors. A complete historical overview of the Site is given in Section 1.2, as well as in the Phase 1 and 2 reports (Roux Associates, 1983; 1984).

4.1.1 Previous Investigations
RI/FS Phase 1 and 2 Reports

Although investigations designed to identify the nature and extent of the waste deposits were initiated as far back as 1972, the bulk of the pertinent information on the Site was developed in the Phase 1 and Phase 2 Remedial Investigation (Roux Associates, 1983;1984).

During the Phase 1 study the Site was surveyed, observation wells were installed, test pits were dug and soil borings were completed. Air, soil, ground water, surface water, sediment, and waste piles were sampled. Samples of these media were analyzed for the presence of priority pollutants. The report concludes that soils with metals of concern are primarily located west of Commerce Way and north of the Hall's Brook Holding Area. Twenty-two acres contained greater than 1000 mg/kg arsenic and lead; five acres contained less than 1000 mg/kg chromium. Barium, copper, and zinc were found at lesser concentrations, but were more widely distributed. Eight acres of the Site contained hide residues.

Ground-water flow direction is generally from north to south, and analyses of well water showed the presence of metals and VOCs. Surface-water analyses detected metals and VOCs. Sediment samples were observed to contain arsenic, lead, copper, and zinc (VOCs were also detected).

The Phase 2 study addressed data gaps identified during Phase 1 and extended the Study Area. Data collected during Phase 2 allowed more accurate mapping of hide residues and soil metals. As in Phase 1, constituents of concern in soils were predominantly lead, arsenic, zinc, copper, and chromium. Lead and arsenic were generally detected concomitantly, while chromium was usually found to be associated with the hide residues. Other toxic constituents (e.g. mercury, cadmium) were found infrequently and were localized in small areas. Extraction Procedure toxicity tests showed that soil metals had little propensity for dissolution into water.

In the Phase 2 portion of the RI/FS, an "endangerment assessment" (health risk assessment), was performed. This baseline assessment addressed potential exposure of humans to constituents of concern (COC) in ground water, air, and soil. Results of this assessment suggested that metals in ground water were fairly immobile and would not be of concern, but that exposure as a result of soil ingestion would pose an increased risk to humans. Modeling of gases emitted from hide pile residues showed that the odor threshold for hydrogen sulfide may be exceeded during "worst-case" emission rates.

Wetland Evaluations

A thorough investigation of the floodplain and wetlands associated with the Aberjona River was performed in July of 1986 (Wetlands Management Specialists, Inc., 1986). The investigation identified both on-site and off-site water bodies, catalogued flora and fauna, delineated upland/wetland boundaries, and described individual habitats present within each wetland. In addition to the previous observations, each wetland was evaluated for wildlife production and diversity, and water quality protection and renovation.

The investigation concluded that the Lower South Pond, the Hall's Brook Holding Area, the unnamed pond near the Site Trailers, and an isolated wetland west of Commerce Way received good scores with regard to structural diversity, size, vegetative interspersion, and proximity to open water. Remaining wetlands received fair to poor scores.

The following areas all received high scores with regard to vegetational structure, water regime, size, and the ability to intercept polluted waters:

- the Hall's Brook Holding Area;
- the wetland directly north of, and adjacent to, the Woburn Mall Parking Lot;
- an isolated wetland east of Commerce Way; and
- the Atlantic Avenue drainway (feeding into the Hall's Brook Holding Area).

A more in-depth "functional analysis" of the Lower South Pond was performed as part of the PDI requirements (NAI, 1990). This study employed a semiquantitative model based on data derived from over 1000 regional wetland systems. It evaluated the functional parameters of the Lower South Pond that give rise to public benefit (e.g. flood control, hydrologic support, wildlife contribution). In addition, the report catalogued various plant and animal species observed in the area.

The final analysis modified the results of the model, based on observation and professional judgement. It concluded that the Lower South Pond ranked high for hydrologic support, moderate for wildlife, floodwater storage, shoreline protection, and water-quality maintenance, and low for ground-water recharge, recreation, aesthetic value, and education.

4.2 Data Evaluation

The first step in a human health risk assessment or ecological evaluation is the tabulation and statistical evaluation of the chemical and physical data gathered during field investigations. Because this initial data evaluation step is similar for both types of "risk assessments" (USEPA, 1989a, c, e), they are combined in the present report.

4.2.1 Database

Data used for this portion of the GSIP RI was received from Roux Associates, Inc. of Huntington, NY. It was developed from laboratory analyses (Enseco-ERCO, Cambridge, MA) of ground-water, sediment, and surface-water samples. These samples were taken during the spring and summer of 1990 to fulfill, in part, the requirements of the GSIP RI. For completeness, data analyzed to fulfill requirements for the PDI Work Plan were also utilized in this data base. A map illustrating the Site boundaries and the location of each sampling station is provided in Volume 2 of this document (Plate 1).

Ground-water and surface-water samples were analyzed for the presence of metals, pesticides and PCB's, VOCs and SVOCs (both total and dissolved water samples were analyzed for metals. For this assessment, all values were included in the data base with the exception of those qualified as unusable data. Data validation procedures were performed in accordance with USEPA Region I data validation guidelines, and as documented by the GSIP RI Work Plan. Data validation documentation is presented in Appendix D.

Statistical evaluations were also performed for each class of constituents and the results were tabulated (Table 4.1 through 4.14 and Appendix G). Based on the observation that the frequency distributions of the majority of constituents showed significant departures from normality (Lillifor's Test), a geometric mean was chosen as the best estimate of central tendency.

The data described below were used for selection of indicator compounds and subsequent human health and environmental risk analysis. Only data from sampling rounds conducted as part of the approved GSIP RI and PDI Work Plan were utilized. While earlier data on different media at the Site exist (Roux Associates, 1983;1984), they do not reflect current conditions at the Site, and did not undergo any type of quality control procedure or validation process. The data presented here are believed to be sufficient for selection of indicator compounds, and to address current and future risk at the Site. The approved GSIP RI Work Plan was designed to sample background (upstream or upgradient) locations, as well as areas suspected of being influenced by suspected sources of constituents of concern. This design was based on previous studies, aerial photos, and historical data on Site use, rather than relying on a random sampling scheme. Thus, use of these data for hazard identification and subsequent health risk assessment should adequately cover potential impacts of the Site.

4.2.2 Surface Water

One goal of the risk assessment is to assist in the remedial decision making process. However, this risk assessment is unique in that a ROD is already in place, which, in turn, obviates the need for constructing exposure scenarios and calculating risk estimates for several locations. The following surface-water stations are located within areas that have already been targeted for remedial actions:

SW-1
SW-2
SW-7
SW-15
SW-16
SW-17

Although data developed for these locations are included in the calculation of descriptive statistics, they will not be considered as locations of concern with regard to the exposure or risk estimation.

Metals

Because metals are ubiquitous, it is necessary to sample areas that would not be considered to be influenced by constituents present at the Site. Concentrations of metals in these "background" or "reference" areas (usually upstream or upgradient from the Site) can then be compared to samples taken from the suspected impact area. This approach was taken for the evaluation of metal concentrations in surface waters at the Site, with stations SW-1, SW-4, and SW-8 designated as the upstream "reference" samples. The remaining stations were located on, or downstream, of the Site, and were designated as "Site". A total of fifteen surface-water samples were analyzed. Two stations, SW-3 and SW-16 were dry at the time of sampling.

Descriptive statistics for total metals measured in surface water are presented in Table 4.1. Beryllium, cadmium, mercury, nickel, selenium, thallium, vanadium, and tin were not detected in any sample. Aluminum, copper and silver were detected in less than 50 percent of the samples. Antimony, cobalt, and silver were detected near their respective detection limits in less than 15 percent of the samples. Total metals in surface water, *relative to the mean reference concentrations*, were ranked as follows, arsenic > manganese > potassium > chromium > iron. Maximum values for total metals were recorded in surface waters draining Site areas west of the railroad tracks (SW-6, SW-7, SW-9, SW-10, and SW-15) while the maximum value for arsenic was recorded in the stream draining the Lower South Pond.

Descriptive statistics for dissolved metals measured in surface water are presented in Table 4.2. Beryllium, cadmium, chromium, cobalt, lead, mercury, nickel, selenium, silver, thallium, vanadium, and tin were not detected in any sample. Antimony, copper, and silver were detected near their respective detection limits in less than 25 percent of the samples. Dissolved metals in surface water, *relative to the mean reference concentrations,* were ranked as follows, zinc > manganese > arsenic > aluminum > barium. The maximum dissolved metal concentrations were also recorded in surface waters draining the western portion of the Site (SW-6, SW-7, SW-9, and SW-15) while the maximum concentration for arsenic was recorded in the stream which drains the Lower South Pond.

Volatile Organic Compounds

VOCs were detected infrequently in surface water (Table 4.3). Acetone, chlorobenzene, 1,1-dichloroethane, toluene, 1,1,1-trichloroethane, and xylenes were detected (near detection limit) in less than 15 percent of the samples taken. Methylene chloride was detected most frequently (8 of 15 samples). 1,2-Dichloroethene and trichloroethene both had maximum values of 11 μg/L. The maximum concentrations of VOCs were recorded in the Hall's Brook Holding Area and locations west of the railroad tracks (SW-6, SW-7, SW-9, SW-11, SW-13).

Semi-Volatile Organic Compounds

SVOCs were also detected infrequently and at concentrations near the limit of detection (Table 4.4). Butylbenzylphthalate, di-n-butylphthalate, and N-nitrosodiphenylamine were detected in less than 7 percent of the samples, all at concentrations below the instrument detection limit. Bis(2-ethylhexyl)phthalate was detected in one-third of the samples, with the maximum concentration (12 μg/L) measured in the Hall's Brook Holding Area.

Pesticides and PCB Compounds

Organic pesticide and PCB compounds were not detected in surface-water samples, but these data were subsequently validated as "unusable". However, data developed during the PDI also indicated that these compounds were not present in the media tested. Based on the history of past activities at the Site and available information, this class of chemicals was not further evaluated.

Selected Physical and Chemical Parameters

Although not typically included in the risk assessment process, selected chemical and physical parameters measured in surface water have been tabulated (Table 4.5) to assist in the evaluation of water quality. Outflow from areas west of the railroad tracks (SW-6, SW-7, and SW-10) had the maximum levels of alkalinity, chloride, hardness, total organic carbon, phosphate, and sulfate. The water sample taken at SW-2 recorded the maximum value for chemical oxygen demand.

4.2.3 Sediment

One goal of the risk assessment is to assist in the remedial decision making process. However, this risk assessment is unique in that a ROD is already in place, which, in turn, obviates the need for constructing exposure scenarios and calculating risk estimates for several locations. The following surface-water stations are located within areas that have already been targeted for remedial action:

SW-1

SW-2

SW-7

SW-15

SW-16

SW-17

Although data developed for these locations are included in the calculation of descriptive statistics, they will not be considered as locations of concern with regard to exposure or risk estimation.

Metals

Because of the role that arsenic, lead, and chromium have played at the Site, it was decided to include the PDI results of sediment analyses for these compounds, in the database used for the risk assessment. Exposure to constituents of concern in sediment below a depth of 6 inches, in view of the current exposure scenarios developed for the health risk assessment, would not be anticipated. Therefore, metal concentrations at each PDI sampling station were

calculated by taking the average of three samples (taken in a transect running perpendicular to the streamflow) and only using analyses from the top 6 inches of sediment. The complete data base used for generating descriptive statistics seen in Table 4.6 is presented in Appendix G.

Because metals are ubiquitous, it was necessary to sample areas that would not be considered to be influenced by constituents present at the Site. Concentrations of metals in these "background" or "reference" areas (usually upstream or upgradient from the Site) can then be compared to samples taken from the suspected impact area. This approach was taken for evaluation of metal concentrations in sediment at the Site. Reference sample locations included areas that are upstream of the Site or areas considered "clean" based on past investigations performed at the Site. For the GSIP RI data base, this includes SW-1, SW-3, SW-4, and SW-8, and for the PDI database includes SW-1/040, SW-1/042, SW-1/047, SW-1/049, SW-1/052, SW-1/055, SW-1/057, and SW-1/059. All stations exclusive of the reference areas are designated as "Site" in this risk assessment.

The size of the data base for metals was sufficient to construct frequency distributions to allow the reader to gain more insight on the number of "hits" falling within a particular concentration range. These tables are presented in Appendix G.

Table 4.6 presents descriptive statistics for metals in sediment. Matrix elements commonly found in the earth's crust (aluminum, calcium, iron, magnesium, manganese, sodium, and potassium), as well as several trace elements (arsenic, barium, chromium, cobalt, copper, lead, tin, vanadium, and zinc) were detected in greater than 90 percent of the samples. Antimony, beryllium, cadmium, mercury, nickel, selenium, silver, and thallium were detected less frequently.

To gain perspective on the concentration of each metal relative to background concentration, a ratio was calculated by dividing the mean concentration of the Site areas by the mean concentration of the reference areas. These ratios were then sorted according to rank (Table 4.6). *Relative to mean reference area concentrations*, the metals ranked as follows, arsenic > lead > zinc > chromium > copper > barium. The previous RI/FS reports (Roux Associates, 1983;1984) concluded that these elements were the predominant metals in *soil*

samples taken from the Site. Indeed, upon close inspection of the data base, it can be seen that locations of *sediment* metal concentrations generally correlate with locations of *soil* concentrations (e.g. New Boston Street Drainway, Lower South Pond, and Hall's Brook Holding Area).

As observed in Table 4.6, 15 of the 24 metals analyzed had maximum concentrations in sediment samples dredged from the Hall's Brook Holding Area (SW-9 and SW-11). This is partially due to the fact that the Hall's Brook Holding Area receives runoff from areas that exceed C.D. action levels for metals and have already been targeted for remediation (Roux Associates, 1983;1984). However, this does not explain increased concentrations of other elements (e.g. aluminum, cadmium, beryllium, calcium, magnesium, nickel, potassium, sodium) that have not been identified in past studies as a Site-related concern. This is because, unlike other locations, the Hall's Brook Holding Area sediments contain a much greater percentage of silts/clays (grain size analysis, Table 3-19). Silts and clays have a much higher surface/volume ratio and thus a greater cation exchange capacity, which will tend to bind and concentrate metals (Horowitz, 1991). Closer inspection of the data reveals that, for the Hall's Brook Holding Area, Site-related metals (e.g. copper, zinc) tend to increase proportionally with other metals not shown to be associated with the Site (e.g. beryllium, aluminum), which lends further support to this observation.

Some metals were seen to be positively correlated with others in sediment. Table GI-E (Appendix G) presents a correlation matrix (Pearson's) containing sediment metal concentration data for aluminum, arsenic, barium, cadmium, calcium, chromium, cobalt, copper, iron, lead, magnesium, manganese, mercury, potassium, sodium, vanadium, tin, and zinc (the reader must use care in the interpretation of correlations for cadmium and mercury, as these elements had missing values). Prior to the statistical analysis each metal concentration was adjusted for grain size by multiplying by a "dilution" factor (100 percent less than 125 μm). Arsenic was found to be positively correlated (p = 0.001) with chromium, copper, lead, and zinc. Other metals, such as iron, calcium, cobalt, and vanadium, also had statistically significant correlations with many of the metals tested.

Volatile Organic Compounds

Thirteen different VOCs were detected in sediment, with roughly half of these matching compounds detected in the surface-water suite of analyses (Table 4.7). 1,2-Dichloroethane, 1,2-dichloroethene, 2-hexanone, and 4-methyl-2-pentanone were detected infrequently or at concentrations near the limit of detection. Methylene chloride was detected most frequently, while benzene was detected at a maximum concentration of 2,100 μg/kg at SW-11. Again, samples with the maximum concentrations of each constituent were primarily located on the western portion of the Site (SW-6, SW-7, SW-15) and the Hall's Brook Holding Area (SW-9, SW-11, and SW-13).

Semi-Volatile Organic Compounds

Table 4.8 presents descriptive statistics for SVOCs in sediment. Twenty-two compounds were identified, but more than half of these constituents were polynuclear aromatic hydrocarbons (PAH's). Benzoic acid, butylbenzylphthalate, 3,3'-dichlorobenzidine, 2,4-dinitrotoluene, N-nitrodisodi-phenylamine, acenaphthylene, and fluorene were found in less than 6 percent of the samples. Bis(2-ethylhexyl)phthalate had a maximum concentration of 90,000 μg/kg at SW-7. Maximum concentrations of PAH compounds were seen at SW-12, SW-15, and SW-16. Geometric mean concentrations for this class of compounds ranged from 2 to 185 μg/kg, which falls within the concentration range reported for PAH's in *soils* in industrially zoned areas (Norton, 1990).

Pesticides and PCB Compounds

Organic pesticide and PCB compounds were not detected in sediment samples, but these data were subsequently validated as "unusable". However, data developed during the PDI investigation, also suggested that these compounds were not present in the media tested. Based on the history of past activities at the Site and the available information, this class of chemicals was not further evaluated.

Selected Physical and Chemical Parameters

Table 4.9 presents summary statistics for selected physical and chemical parameters in sediment. SW-16 had the greatest percentage of total organic carbon, which may explain why this location had, relative to other stations, higher levels of PAHs (PAH's have a very high affinity for organic material). SW-9 had the maximum concentration of trivalent and

hexavalent chromium recorded, with the latter (which is considered to be more toxic than the former) comprising less than 1 percent of the total chromium. SW-6 had the maximum pH value (7.9), while the minimum was observed at SW-3 (5.8).

4.2.4 Ground Water

Ground-water data from three separate sampling rounds (March, June, and October 1990) were utilized in this risk assessment. A total of 42 wells were sampled to yield (with the exception of PCB/pesticides and SVOCs 65 separate ground-water quality analyses. Two separate sampling rounds were conducted for the determination of arsenic, barium, and zinc. For this assessment, only the most recent arsenic, barium, and zinc data (August 1990) were used as they were regarded as most representative.

Metals

Because metals are ubiquitous, it is necessary to sample areas that would not be considered to be influenced by constituents present at the Site. Concentrations of metals in these "background" or "reference" areas (usually upstream or upgradient from the Site) can then be compared to samples taken from the suspected impact area. Observation wells OW-1, OW-1A, OW-21, and OW-4 were designated as the upgradient reference areas at the Site. Other locations sampled during the GSIP RI were considered as areas that may be potentially impacted by the Site.

Table 4.10 presents descriptive statistics for total metals in ground-water samples. Beryllium, cadmium, mercury, silver, and thallium were detected infrequently, while tin was not detected in any sample. Matrix elements (aluminum, calcium, iron, magnesium, manganese, sodium, potassium) were detected in greater than 90 percent of the samples taken.

To evaluate the concentration of each metal recorded in ground-water samples relative to background concentration, a ratio was calculated by dividing the mean concentration of the Site areas by the mean concentration of the reference areas. These ratios were then sorted according to rank. The following elements were ranked (for purposes of the hazard identification) *relative to the mean background concentrations*, arsenic > > zinc > barium > lead > vanadium > iron > chromium (Note: vanadium, a rare element, had a biased rank due to an outlying value of 370 μg/L at OW-28; it was not detected (IDL = 6 μg/L) at this

well for the dissolved suite of analyses). Of the 23 metals analyzed, 5 had maxima at OW-28, however there is a strong indication that this is due to suspended sediment since dissolved samples from these wells did not yield maximal values (Table 4.11). OW-16, OW-31 and OW-32 are located within buried hide wastes and samples from these wells showed concentrations of chromium. Arsenic, barium, and vanadium were also present. Maximum concentrations of copper (1350 μg/L), lead (299 μg/L), and zinc (9970 μg/L) were seen at OW-10, OW-14, and OW-10, respectively.

Table 4.11 presents descriptive statistics for dissolved metals in ground-water samples. Cadmium, cobalt, lead, selenium, silver, thallium, and tin, had a low frequency of detection (11 of 65 samples). Beryllium and mercury, were not detected above the instrument limit of detection. Matrix elements (calcium, barium, magnesium, manganese, sodium) were detected in greater then 90 percent of the samples taken.

To evaluate the concentration of each metal relative to upgradient wells, a ratio was calculated by dividing the mean concentration of the Site areas by the mean concentration of the reference areas. These ratios were then sorted according to rank. The following elements were ranked (for purposes of the hazard identification) *relative to the mean background concentrations,* iron > > arsenic > chromium > zinc > barium. Although there is a change in rank between the total and dissolved metal suite, arsenic, barium, chromium, iron, and zinc still rank within the top seven compounds.

Dissolved metal concentrations, in general, followed the same general trend as seen for total metals. OW-16, OW-31 and OW-32 (located within buried hide wastes) still had, relative to upgradient wells, higher levels of arsenic, barium, chromium, and vanadium, while higher concentrations of copper and zinc were observed on OW-18 and OW-10. Although OW-14 had the maximum value for lead, it appears that the particulate (>0.45 micron) phase is primarily responsible for the observed values. Manganese and iron, typically found in ground water, had maxima at OW-32 and OW-42, respectively.

Volatile Organic Compounds

Sixteen different VOCs were detected in ground-water samples (Table 4.12). Seven of these (chloromethane, 1,2-dichloroethane, 1,1-dichloroethene, trans-1,2-dichloroethene,

chlorobenzene, chloroethane, methylene chloride) were found in less than 5 percent of the samples. The maximum for benzene was found at OW-31 (located in the West Hide Pile), while toluene was detected most frequently (19 of 66 samples), with a maximum of 32,000 μg/L at OW-16 (within the East Central Hide Pile). Maximum values for ethylbenzene and xylenes (6 and 35 μg/L, respectively) were seen at OW-9. Maximum values for 1,1-dichloroethene, trichloroethene, and 1,1,1-trichloroethane were found at OW-26B.

Semi-Volatile Organic Compounds

Six SVOCs were detected in ground water (Table 4.13). Benzoic acid and 4-methylphenol (m-cresol) had maximum concentrations of 2000 and 3400 μg/L, respectively, but as with acenaphthene and 2-methylphenol (o-cresol), were detected infrequently (2 of 38 samples). Four out of the six compounds had maximum concentrations detected at OW-16. Acenaphthene and 2-methylphenol were both detected near their limits of detection (3 to 5 μg/L)

Pesticides and PCB Compounds

Organic pesticide and PCB compounds not detected in ground-water samples, but results from these data were subsequently validated as "unusable". Data developed during the PDI however, also suggested that these compounds were not present in the various media tested. Based on the history of past activities at the Site and the available information, this class of chemicals was not further evaluated.

Selected Physical and Chemical Parameters

Although not typically included in the risk assessment process, selected chemical and physical parameters measured in ground water have been tabulated (Table 4.14) to assist in the evaluation of water quality. Measurements of pH were, for the most part, circumneutral. The most acidic reading was at OW-10 (5.34), while the most basic ground water was found at OW-16. OW-16 is located within buried hide deposits and had the maximum measured values for conductivity, bicarbonate, sulfide, total organic carbon, and phosphorus. To assist with the metals mobility portion of the GSIP RI (Sections 2.4 and 3.5), a correlation matrix of these parameters (dissolved samples only) was generated (Table 4-5). It can be seen that there are some statistically significant positive linear relationships for many of the constituents present in the ground water. This table shows, as expected, that:

- conductivity appears to be a good predictor of total dissolved solids in ground water;

- arsenic, magnesium, potassium, bicarbonate, phosphate, and total organic carbon are generally found together and in the same relative proportions;

- there was an inverse relationship between Eh and pH; and

- in addition to calcium and magnesium, sulfate contributed to measured hardness.

4.3 Human Health Risk Assessment

This health risk assessment was conducted to determine the potential for constituents of concern present within the Study Area to adversely affect human health, given several theoretical exposure scenarios. It consists of four principal components namely hazard identification, toxicity assessment, exposure assessment, and risk characterization. The reader is referred to the risk assessment guidance (USEPA, 1989a,c) for a more in-depth discussion of each component, and to the GSIP RI Work Plan where the methodology may differ from the latter.

4.3.1 Hazard Identification

It is sometimes necessary to limit the number of chemicals used in the quantitative risk analysis to reduce the complexity of the analyses and to focus on compounds that are likely to present an increased potential for risk at the Site. This process is referred to as hazard identification and is documented below for the Industri-Plex Site.

4.3.1.1 Methodology

Methods for development of hazard identification (HI) were taken from USEPA guidance for the evaluation of human health risk (USEPA, 1989a/c). This guidance suggests that certain criteria be used to determine whether a particular constituent be included or omitted from the risk assessment. These criteria include: toxicity of the compound, frequency of detection, background concentration, environmental persistence, mobility, fate and transport processes, and the quality of the database. Although this assessment primarily relied on comparisons of Site concentrations to reference (or background) levels, a toxicity screening method was also employed. This is conservative method which calculates the ratio of the maximum concentration of each constituent of concern to its respective toxicity value and ranks results in descending order. State and Federal standards and criteria relevant to each media were also used to screen analytical findings with respect to potential health impact.

In addition to these selection parameters, it is important to recognize that the health impact of a chemical is directly related to the potential for a receptor to be exposed. Thus, the location of each constituent weighed heavily in the HI process.

Finally, the professional opinion of an experienced toxicologist was used to identify inconsistencies in the data base, evaluate and compare available criteria, and to make the final choice of "indicator chemicals" to be used in this risk assessment.

Table 4.15, 4.16, and 4.17 identify the different classes of compounds (metals, VOCs and SVOCs, respectively) and the different media in which these compounds were detected to assist in the selection process. Criteria by which each compound was eliminated from the HI are listed for each constituent and each medium. These criteria include the frequency of detection, the concentration (generally judged relative to background or proximity to the detection limits), toxicity, location, and the availability of quantitative information for evaluation of risk.

It is known that natural background of metals in surface waters and sediments, with respect to the mean value, can generally vary by two to five fold (Shacklette and Boerngen, 1984; Baudo et al., 1990). Consequently, with regard to evaluating the ranking of elements based on the Site area/reference area mean ratios, an arbitrary cutoff value of 2 was chosen as a plausible threshold criteria.

4.3.1.2 Surface Water

Metals

Of the metals detected in surface water, only antimony, arsenic, barium, chromium, cobalt, and lead have the potential to cause adverse effects in humans at environmentally relevant concentrations. Aluminum, calcium, copper, iron, magnesium, manganese, potassium, sodium, and zinc are all normal components of the human diet and would be considered to be virtually non-toxic at the levels seen in surface water at the Site. Therefore, these metals were eliminated from consideration in this risk assessment (USEPA, 1989c, Section 5.9.4).

Table 4.15 lists criteria used to assist in the selection process for metals in surface water. Antimony and cobalt were eliminated based on the fact that they both had a low frequency

of detection and received a low ranking relative to reference concentrations. Barium was eliminated based on its low solubility and toxicity. Beryllium, cadmium, mercury, nickel, selenium, thallium, tin, and vanadium were not detected in either the dissolved or total sample analyses.

The remaining metals can be considered indicator compounds for inclusion in the human health portion of the risk assessment:

- Arsenic
- Chromium
- Lead

Volatile Organic Compounds

Table 4.16 lists criteria used to assist in the selection process for VOCs in surface water. Generally, VOCs were found near the limit of detection in surface water. Of the constituents listed in Table 4.3, acetone, chlorobenzene, 1,1-dichloroethane, toluene, and xylene were eliminated from consideration based on their low frequency of detection (2 of 15 samples) and concentration (all five were below the CRQL and at or very close to the IDL.

The compounds chosen for consideration in the evaluation of health risk as a result of exposure to surface water are:

- 1,2-Dichloroethene
- Methylene Chloride
- 1,1,1-Trichloroethane
- Trichloroethene

Semi-Volatile Organic Compounds

Table 4.16 lists criteria used to assist in the selection process for SVOCs in surface water. Butylbenzylphthalate, di-n-butylphthalate, and N-nitrosodiphenylamine were omitted due to the low frequency of detection (1 of 15 samples) and concentration (all were detected below 5 μg/L). Although diethylphthalate was detected more frequently (3 of 15 samples), the maximum value falls below the IDL. The compound chosen as the constituent of concern for the evaluation of SVOCs to human health in surface water is bis(2-ethylhexyl)phthalate.

4.3.1.3 Sediment

<u>Metals</u>

Table 4.15 lists criteria used to assist in the selection process for metals in sediment. Of the metals detected in sediment, antimony, arsenic, barium, beryllium, cadmium, chromium, lead, mercury, nickel, selenium, and thallium have the greatest potential to cause adverse effects following human exposure. Toxic responses as a result of the ingestion of aluminum, calcium, cobalt, copper, iron, magnesium, manganese, potassium, silver, sodium, tin, vanadium, and zinc are rarely seen and then only in very unusual circumstances (USEPA). Therefore, these metals can be eliminated from consideration (USEPA, 1989c, Section 5.9.4) in this risk assessment.

Antimony, beryllium, nickel, selenium, thallium, and vanadium were not considered in this risk assessment because the mean values were very close to the IDL, and the mean Site/reference area ratios were less than 2.0. Barium ranked fairly low in toxicity and is generally present in an insoluble, (e.g. $BaSO_4$) non-toxic form in natural waters. Although outliers did exist for these compounds (Table G-1B2 - Appendix G), these concentrations were recorded in areas already identified for remedial action.

The remaining constituents will be considered as indicator chemicals for the evaluation of the sediment exposure pathway to humans:

- Arsenic
- Cadmium
- Chromium
- Lead
- Mercury

<u>Volatile Organic Compounds</u>

Table 4.16 lists criteria used to assist in the selection process for VOCs in sediment. Chlorobenzene, 1,2-dichloroethane, 1,2-dichloroethene, 2-hexanone, and 4-methyl-2-pentanone had low frequencies of detection (1 of 19 samples tested). 1,2-Dichloroethene, 2-hexanone, 4-methyl-2-pentanone, and trichloroethene concentrations were close to the detection limit.

Although some sediment samples contained chlorobenzene, tetrachloroethene, toluene, and trichloroethene, the locations of these positive samples (e.g. New Boston Street drainage) are not considered as areas with potential for recreational bathing. Given the above criteria, the aforementioned compounds will not be included as constituents of concern for the health risk assessment.

Human exposure to VOCs via a sediment exposure pathway (recreational bathing) will be calculated for the remaining detected VOCs. The constituents of concern are:

- Acetone
- Benzene
- 2-Butanone
- Ethylbenzene
- Methylene Chloride

Semi-Volatile Organic Compounds

Table 4.17 lists criteria used to assist in the selection process for SVOCs in sediment. Benzoic acid, butylbenzylphthalate, dibenzofuran, 3,3'-dichlorobenzidine, 2,4-dinitrotoluene, and N-nitrosodiphenylamine were detected infrequently (2 of 19 samples) and at locations that would not be considered conducive for recreational bathing. Thus, these compounds will not be selected as constituents of concern.

Fifteen PAH compounds were detected. Acenaphthylene and fluorene were detected in one sample (SW-15), which was in a stream that is fairly inaccessible. Acenaphthene, anthracene, benzo(g,h,i)perylene, and phenanthrene were eliminated from the risk assessment based on the lack of available toxicity information. The remainder of the PAH compounds were included in the evaluation of health risk.

The following compounds are to be considered constituents of concern for SVOCs in sediment:

- bis(2-Ethylhexyl)phthalate
- Diethylphthalate
- Benzo(a)anthracene
- Benzo(a)pyrene
- Benzo(b)fluoranthene

- Benzo(k)fluoranthene
- Chrysene
- Dibenzo(a,h)anthracene
- Fluoranthene
- Indeno(1,2,3-cd)pyrene
- Pyrene

4.3.1.4 Ground Water

Metals

Of the metals detected in ground water, antimony, arsenic, barium, beryllium, cadmium, chromium, lead, mercury, nickel, selenium, thallium, and zinc have the greatest potential to cause adverse effects following human exposure. Toxic responses as a result of the ingestion of aluminum, calcium, cobalt, copper, iron, magnesium, manganese, potassium, silver, sodium, tin, and vanadium are rarely seen and then only in very unusual circumstances. Therefore, these metals can be eliminated from consideration (USEPA, 1989c, Section 5.9.4) in this risk assessment.

Table 4.15 lists criteria used to assist in the selection process for metals in ground water. Beryllium, cobalt, mercury, silver, and thallium had mean Site/reference ratios that approached unity (thallium was detected twice, while beryllium and mercury were not detected in the dissolved analyses). Selenium had a fairly low frequency of detection and the mean Site/reference concentration was below 2.0. Vanadium was detected frequently, but the mean was strongly biased as a result of a single outlier (OW-28). Given the data and the evaluation of the descriptive statistics, the aforementioned elements were excluded from the risk assessment.

In addition to the hazard ranking analysis presented above, a toxicity screening method outlined in the risk assessment guidance (USEPA, 1989c), was used at the request of the USEPA. This method is conservative in that it ranks each chemical using the maximum detected concentration. Results of this procedure are presented in Appendix G.

Based upon these evaluations, the following metals will be designated as indicator compounds in ground water:

- Arsenic
- Antimony
- Barium
- Cadmium
- Chromium
- Lead
- Mercury
- Nickel
- Zinc

Volatile Organic Compounds

Table 4.16 lists criteria used to assist in the selection process for VOCs in ground water. Acetone and ethylbenzene were eliminated based on low concentration and frequency of detection. Chlorobenzene and chloromethane were detected only in ground water from OW-1, considered upgradient from the Site.

The following VOCs were identified as constituents of concern in ground water:

- Benzene
- Chloroform
- 1,1-Dichloroethane
- 1,1-Dichloroethene
- 1,2-Dichloroethane
- Methylene Chloride
- Toluene
- 1,1,1-Trichloroethane
- Trichloroethene
- Xylenes (total)

Semi-Volatile Organic Compounds

Table 4.17 lists criteria used to assist in the selection process for SVOCs in ground water. Acenaphthene and 2-methylphenol were eliminated based on low frequency of detection and

concentration and were not considered in this risk assessment. Bis(2-ethylhexyl)phthalate was generally found near the detection limit and was eliminated for that reason. Finally, the majority of SVOCs were identified in samples taken from on-site wells (OW-16, OW-31) that were developed within buried hide waste. These areas are upgradient of the pump-and-treat remedy currently at the 60 percent design stage.

Consequently, SVOCs considered for inclusion in the risk assessment will be:
- Benzoic Acid
- 4-Methylphenol (p-cresol)
- Phenol

4.3.2 Toxicity Assessment

Methods used to determine toxicity values for the constituents of concern employed in this risk assessment are described below.

4.3.2.1 Introduction

Toxicity is a measure of a chemical's capacity to damage an organism. The fundamental principle of toxicology is that adverse effects of chemicals are dose-related. As the dose (the exposure magnitude) of a chemical increases, the probability that an individual will suffer toxic effects (risk) increases. Each chemical has its own specific "dose-response curve" that describes this relationship.

There are two features of the dose-response curve that may be used in this risk assessment. If one knows the slope of the dose-response curve, it is possible to quantify risk for any given dose and if one knows the x-intercept of the curve (i.e., the point at which toxic risk is zero) one may characterize a given dose as being above or below an apparent "threshold" for the toxic action. The latter is not a risk calculation, rather it is a discrete, yes-no assessment of whether a toxic event will occur. Typically, risk calculations using dose-response slopes are conducted for chemicals that may cause cancer in humans. For chemicals having other toxic actions, a comparison of estimated exposures to doses presumed to be safe is used.

Quantitative toxicity data for health risk assessment are derived from observations of toxic effects in humans accidentally exposed to chemicals, or from observations of deliberately-dosed

experimental animals. Toxicology experiments are costly and time-consuming and experimental toxicity data are rarely generated specifically for a single environmental assessment. As a matter of practicality, toxicity information is kept in a variety of data bases for use in health risk assessment. While the methods for determining toxicity values for the chemicals of concern are described here, the data were, in fact, obtained primarily from the Health Effects Assessment Summary Tables for the 1st quarter of 1991 (USEPA, 1991).

4.3.2.2 Risk Assessment of Carcinogens

Some theories for the mechanism by which certain chemicals cause cancer (particularly those where a direct action on genetic material is hypothesized) suggest that there would be no dose of these chemicals that was without some risk of producing cancer. The prudent assumption used for most risk assessments is that this no-threshold condition exists for all carcinogens. Under this assumption, the only toxicity value that can be obtained is the dose-response slope. The slope of a dose-response curve may be determined by applying any of a variety of mathematical curve fitting techniques to the experimental observations. The methods usually used by the USEPA Carcinogen Assessment Group make the assumptions of no threshold and linear response at low doses. Conservative assumptions are made in determining cancer potency slopes. Cancer potency slopes are usually set at the upper 95 percent confidence bound on the slope predicted by the curve fitting routines. Because the potency slope is linear (i.e., it is in units of increased risk per milligram of chemical to which one is exposed) one may calculate a cancer risk simply by multiplying the estimated exposure by the response slope.

Very few compounds have been demonstrated unequivocally to be carcinogenic in man. However, studies of chemicals in laboratory animals have shown a variety of chemicals to cause cancer, and it is prudent to assume that animal carcinogens may also cause cancer in humans. As the experimental evidence for cancer production varies in both quantity and quality, the USEPA has developed a weight-of-evidence system for determining the confidence with which findings in human epidemiologic studies or animal experiments may be generally extrapolated to man (the weight-of-evidence for each chemical detected at the Site is indicated in the Toxicity Information Table, 4.18). Chemicals may be rated as:

A   sufficient evidence from epidemiologic studies show that there is a causal association between exposure to the chemical and cancer in humans. These compounds are often referred to by USEPA as "known human carcinogens";

B   limited evidence from epidemiologic studies or sufficient evidence from animals studies (usually positive findings in more than one species) of a causal link. These compounds are often called "probable human carcinogens" and are rated B-1 if the data is from human epidemiology or B-2, if the data is from observations in animals;

C   limited evidence from animal studies of a causal link (usually positive findings in only one species, often where there is controversy over whether the animal is a good "model" for human cancer). These compounds are referred to as "possible human carcinogens";

D   not classified; and

E   no evidence of carcinogenicity in humans.

A difficulty arises in determining at what level of certainty compounds should be assumed to be human carcinogens, or when it is sufficiently unlikely that a compound causes cancer in man that it should be assessed based on some other toxic action. Superfund guidance manuals provide no guidance in this area. The USEPA Office of Drinking Water, in setting drinking water standards (Maximum Contaminant Levels) and guidelines (Maximum Contaminant Level Goals) generally treats A and B weight-of-evidence levels as if they are humans carcinogens, while using other methods for C level and less (the Reference Dose method, as described below). In this risk assessment, the cancer risk has been calculated for all chemicals where a potency factor was available (USEPA, 1991, IRIS database). As this included some C-level carcinogens and compounds where the rating is being reviewed, the current approach may be considered somewhat more conservative than that used by the Office of Drinking Water.

4.3.2.3 Assessment of Other Toxic Actions

Most toxic effects other than cancer are believed to have a threshold. Therefore, one may characterize an exposure to a non-carcinogenic compound as above or below this threshold. However, experimental data do not often provide a precise estimate of the threshold for a compound. The typical procedure for dealing with this uncertainty is to determine a "Reference Dose" (RfD), which is an estimate (with uncertainty spanning perhaps an order of magnitude) of daily exposure to the human population (including sensitive subgroups) that is likely to be without an appreciable risk of deleterious effects during a lifetime (USEPA, 1991). At this level, it is extremely unlikely that any toxic response would be observed, and it may well be that the RfD is substantially below threshold.

Risk characterization using the RfD is done by comparing the estimated exposure to the RfD for each chemical. If the ratio of the estimated exposure to the RfD (this ratio is often called a Hazard Index) is less than 1, then the risk of a health effect is low. Progressively more confidence in the safety of the exposure is obtained as Hazard Indices fall further below unity (1).

Potency Factors and RfD values for the constituents of concern at the Industri-Plex Site are presented in Table 4.18. The toxic effects of each of the constituents of concern and the methods applied to the data to derive quantitative toxicity factors (potency factors and/or RfD values) are described in toxicity profiles presented in Appendix G.

4.3.3 Exposure Assessment

The exposure assessment identifies real and potential exposure pathways, receptors, and concentrations of chemicals at specific exposure points. Exposure is quantified with the aid of "exposure scenarios", which identify human activity patterns that promote exposure (e.g. how much drinking water is ingested per day). Quantitative exposure information is integrated with estimates of toxic potency of the constituents of concern to evaluate potential health risks.

4.3.3.1 Introduction

This exposure assessment evaluates the current conditions of the Site in determining exposure scenarios and the chemical concentrations in media with which humans may make contact.

Exposures as a result of potential future uses of the Site would be considered to be lower than those developed for this risk assessment. This results from the implementation of remedial actions currently in design (installation of a permeable cover over soils with metal concentrations above action levels, interception and treatment of affected ground water, and installation of a gas-collecting cap on the East Hide Pile and treatment of the off gas).

4.3.3.2 Site Features

The general features, location, and history of the Site have already been reviewed (see Section 1.2 and 4.1). The boundaries of the Site and Study Area are illustrated in Figure 1. The Site property is currently surrounded by a tall, chain link fence. Public access to the Site is also discouraged by the presence of a security patrol.

The Study Area includes the Site, plus a large segment of land which extends south to Mishawum Road (Figure 1). This area is industrially zoned and consists almost entirely of industrial and commercial properties. Residential areas are fairly remote in terms of the Study Area. Most houses are located approximately one half mile to the east of the Boston & Main Railroad or south of the Woburn Mall, where traffic is very heavy.

Uncontrolled portions of the Study Area that might pose a risk to the public are not easily accessible. Field staff were routinely questioned by management or security personnel (e.g. Digital) about the nature of their activities in the area. Stands of tall rush surrounding the wetlands made passage difficult. Many locations near heavily developed areas presented physical hazards, such as steep embankments, moving traffic, passing trains, and broken glass.

Land within the Study Area is not used for agricultural purposes. Some employees of businesses adjacent to the Hall's Brook Holding Area and Phillips Pond fish during break or lunch hour. Some of the people questioned were not aware of the history of the Site, but none had any desire to take home "keepers", saying they only fished for sport.

No private or public wells are currently operating on or downgradient of the Site.

4.3.3.3 Conceptual Model of Potential Exposures

In support of the original RI/FS, (Roux Associates, 1983;1984), a baseline "endangerment assessment" was performed, which considered the following potential human exposure routes:

- drinking ground water off-site;
- drinking surface water on-site;
- breathing airborne particulate or VOCs; and
- ingestion and dermal absorption of soil constituents on-site.

The exposure assessment utilized in this risk assessment revisited the ground-water exposure scenario, but used a much more conservative approach by placing potential ground-water receptors within the Study Area. Hazards posed by surface waters were also revisited, however, the scenario only considered exposure by recreational wading or bathing. Fish ingestion, which was not considered in the original endangerment assessment, was considered in this analysis as this pathway is a realistic exposure route. Additionally, inadvertent ingestion of sediment through incidental contact was considered.

An exposure scenario considering personal use of ground water for drinking and household use was included in this assessment as a potential future exposure. The overburden aquifer may be regarded as a potential source to drinking water, although there are circumstances limiting this possibility. The most obvious is that the municipal system is available for water users in the area. Wells G and H, which were located south of Route 128 and west of Route 93, have been closed for over 10 years. This aquifer is overlain by an industrial park, is near two major highways serving industrial transportation needs, and is in contact with surface-water bodies which receive large amounts of urban stormwater runoff. This area has seen industrial activity for more than a century, and ground water from Woburn has achieved notoriety with regard to public health risk. In addition, it appears this aquifer is naturally high in iron and manganese, further limiting suitability as a potable water supply. Based upon these considerations, it is unlikely that the overburden aquifer would qualify as suitable for public needs under State regulations or the wellhead protection plans required by the USEPA Office of Groundwater Protection.

Based on flow data gathered during the GSIP RI, it appears that a large portion of the aquifer is intercepted by the Hall's Brook Holding Area and associated wetlands. These waters are

classified as "B" by the Massachusetts Code of Regulations, and may potentially serve as recreational swimming areas. However, these wetlands have been designed to serve the industrial park for the control of floodwater. It is clear upon inspection that both the Hall's Brook Holding Area and the Lower South Pond are not conducive for recreational bathing. Shoreline areas present physical hazards and would be unattractive to bathers, being composed of soft, deep mud or dense stands of tall rush. Other areas which might be more accessible are located on private property and have fairly steep embankments.

During numerous Site visits, field personnel did not observe children playing in the Study Area. This is most probably due to the nature of the Site and its location. To reach the Site, children would have to travel by bicycle or walk a long distance (greater than one half mile) from residential areas.

Although zoning and deed restrictions would likely preclude use of the property for residences, USEPA requested analysis of the risks of contact with materials in these areas if the frequency and duration of contact were similar to that predicted for residential use. These worst-case exposures were included as being representative of a potential future use scenario, i.e. any future risks would be expected to be lower than these "maximum exposure concentrations".

It is notable that the National Contingency Plan requires that a "reasonable maximum" exposure be considered in the risk assessment, and defines that term such that "only potential exposures that are likely to occur will be included in the assessment of exposures." The preamble to the National Contingency Plan final rule, published in March, 1990 goes on to state that "The assumption of residential land use is not a requirement of the program but rather is an assumption that may be made, based on conservative but realistic scenarios, to ensure remedies that are ultimately selected for the Site will be protective. An assumption of future residential land use may not be justifiable if the probability that the Site will support residential use in the future is small." Finally, the preamble states "Where the likely future land use is unclear, risks assuming residential land use can be compared to risks associated with other land uses, such as industrial, to estimate the consequences if the land is used for something other than the expected future use." This type of comparison is presented in this

risk assessment. If the future residential use of the property can truly be characterized as small, several of the exposure scenarios in this assessment go beyond the requirements of the National Contingency Plan.

The exposure scenarios suggested by this conceptual model of the Site are listed in Table 4.20. Locations mentioned in the exposure model (Hall's Brook Holding Area, Lower South Pond, SW-16, and observation wells south of ISRT property) are presented in Section 1.2.

The subsequent sections of this chapter indicate the data used and assumptions made to develop quantitative exposure estimates of these scenarios.

4.3.3.4 Development of Exposure Scenarios: Locations, Exposure Point Concentrations, and Receptors

Ingestion and Household Use of Ground Water

Presently, there is no use of ground water at the Site. All other downgradient wells (Wells G and H, formerly public wells) have been closed. Only observation wells within the Study Area (developed as part of the requirements for the RI/FS, the GSIP RI and the PDI) have been considered in the current data base and are inventoried in Table 4.19. Wells which are "on-site" are defined as those within the Site boundaries, while those "off-site" are exclusive of the former. In accordance with the GSIP RI Work Plan, only off-site wells were evaluated for potential risk or hazard.

This risk assessment considered a potential future exposure, in which ground water in its present condition is the sole source of water utilized by an individual household for (children and adults) drinking water and bathing. Both the geometric mean and maximum ground-water concentrations detected in the wells (off-site) were used. These values are presented in Table 4.21.

Both dissolved and total ground-water samples were analyzed during the GSIP RI. Analytical data from total samples were used for calculation of exposure concentrations. There is some uncertainty associated with the use of dissolved versus total samples of ground-water samples in determining potential exposure to metals. If a observation well ground-water sample is not dissolved, sediments entrained in the ground water are digested by the acid used to

preserve the sample, and sediment metals are dissolved. There is also reason to believe this sediment would not be present in a well developed for public or private use. Consequently, total samples from an observation well do not adequately simulate a potable water supply, and are expected to overestimate risk.

Recreational Bathing - Wading or Swimming

It is possible that children or adults might gain access to Lower South Pond or the ponded portion of the Hall's Brook Holding Area. The former is shallow (less than 3 feet), with a soft muddy substrate and a dense layer of submerged aquatic plants. Waters of the latter are fairly deep, except for the northern end where the Atlantic Avenue Drainway empties into the pond.

The theoretical exposure scenario developed for these areas would be wading in Lower South Pond or swimming in the Hall's Brook Holding Area. In addition to the potential to absorb constituents of concern through the skin, the scenario also incorporates the incidental ingestion of surface water and sediment. However, as a result of the locations and nature of these water bodies, it would be expected that such activity would be infrequent.

Locations used to calculate exposure concentrations for Lower South Pond include SW-1 and SW-2 (GSIP RI data, water and sediment) and SW-1/024 through SW-1/039, SW-1/041, and SW-1/048 (PDI data, sediment only). Final mean and maximum concentrations are presented in the left hand column of Table 4.22 through 4.23. Locations used to calculate exposure concentrations for the Hall's Brook Holding Area were SW-9, SW-11, SW-13 (and the top 6 inches of the CORE sample, south of SW-13, for sediment). With the exception of the northern and southern end of the Hall's Brook Holding Area, all of these waters are deep (greater than 10 feet) and therefore represent absolute worst-case concentrations. Mean and maximum concentrations for these locations are presented in the left hand column of Table 4.24 through 4.25.

Ingestion of Sediment

Since a number of constituents of concern (e.g. PAH) were detected at SW-16 and the stream bed is dry during the summer months, a potential exists for a child (12 to 14 year old range) to gain access to this area and ingest sediment through incidental contact while playing.

Frequency of exposure for this setting would also be considered to be quite low based upon the location and access to the Site, as previously discussed. Concentrations of constituents of concern recorded at SW-16, are presented in Table 4.26.

Fish Ingestion

Ingestion of fish taken from the Hall's Brook Holding Area is a feasible exposure scenario, although no species of economic importance are present within Lower South Pond. Constituents of concern may partition from surface water into the flesh of the fish, which would eventually be consumed by man. Although the frequency of this activity might be considered to be slightly higher than other scenarios based on field observations, the fish yield from this pond would probably the limiting factor for this exposure route. Concentrations of constituents of concern expected in fish flesh were calculated using available bioconcentration factors (USEPA, 1988) and surface-water concentrations from SW-9, SW-11, and SW-13. These average and maximum exposure concentration values are presented in Tables 4.27 and 4.28.

4.3.3.5 Estimation of Exposure Dose

In this section, specific assumptions required to produce a quantitative estimate of exposure are presented. Summary tables of the estimated exposures are also given. Detailed output of the spreadsheet calculations used to estimate these values are presented in Appendix G.

Ground-Water Ingestion and Household Use

The daily intake of constituents of concern via ingestion of ground water was calculated using USEPA Region I Risk Assessment Guidance (USEPA, 1989). Intake is the product of the water concentration and the average daily water volume intake, adjusted for body weight. Thus, the exposure estimate is in units of milligrams contaminant per kilogram body weight per day (mg/kg/day). The exposure is assumed to last an entire lifetime for carcinogens and is calculated for an adult. For non-carcinogens, the exposure is not pro-rated for a lifetime. The calculation for non-carcinogens is calculated for a child (an ingestion rate of 1 L/day per 10 kg body weight). This is consistent with the calculation used for drinking water health advisories and will always be larger than the exposure in adults.

Incidental exposure to volatile constituents in household tap water may occur via inhalation of VOCs "gassing off" the water during a variety of daily activities (e.g. bathing, clothes washing, shaving).

Equations used for this dose estimation and sample calculations can be found in Appendix G. The assumptions employed in this calculation are as follows.

Ingestion (USEPA, 1989c):

- consumption of 2L/day for a lifetime (70 years) for assessing exposure of carcinogens (exposure for children was pro-rated). Less than lifetime exposures were considered for non-carcinogens, and in these calculations a consumption value of 1 L/day was used for children;
- a RAF (relative absorption factor) of 1 for all constituents of concern;
- an average body weight of 70 kg for adults, 45 kg for young children.

Exposure was also assessed for a more realistic scenario, in which ground water might be consumed by an industrial worker (Appendix G.). The scenario assumed that:

- an industrial worker might ingest 1.4 liters of water per day;
- the exposure duration would be 25 years;
- the exposure frequency would be 250 days per year (50 weeks x 5 days/week);
- inhalation would not be considered as a feasible exposure route as the commercial operations within the Study Area consist of warehouses, light industry, and retail facilities.

Household Water Use (McKone, 1987)

USEPA guidance (USEPA, 1989a) indicates that the exposure to VOCs as a result of household water use is considered equivalent to that produced by consumption. Ground-water VOC concentrations used in the exposure assessment calculations are the geometric mean ("average case"), and maximum ("worst case") for all of the samples taken at the Site. Because the maximum ground-water VOC concentration for each constituent of concern may

not occur simultaneously at a single well for a single "theoretical" household, it is important to recognize that the maximum exposure concentration calculations are extremely conservative. Exposure concentrations for this scenario are given in Table 4.21. All concentrations used are for total metals samples.

<u>Recreational Bathing - Wading or Swimming</u>

Intake of constituents of concern by dermal absorption while wading in shallow ponds (Lower South Pond) or swimming in deep surface-water bodies (Hall's Brook Holding Area) is also considered as a possible exposure route. Dermal absorption via this exposure route is the product of the concentration of each constituent in water, the skin surface area in contact with the water, the length of time spent in the water, and the rate at which chemicals may be absorbed through the skin, adjusted for body weight.

As described in the GSIP RI Work Plan, the method of Vanderslice and Ohanian (1989) was used to calculate dermal permeability constants. Although other values for constants may be available in the guidance (USEPA, 1989a), the use of this method insures consistency within each exposure scenario and eliminates gaps where no data are available. Their work shows that a rough approximation of transfer rates for organic materials can be calculated as a function of the ability of the chemical to transfer from water to an oil, as indicated by the octanol-water partition coefficient (K_{ow}). They suggest that, for K_{ow} less than or equal to 1, the transfer rate is 0.001 cm/hour, while for K_{ow}s equal to or greater than 500, the value is 0.1 cm/hour. Between these values the transfer rate is approximated by ($K_{ow}^{0.74}$)/1000 cm/hour. If these values are applied to a unit concentration (1000 mg/cm^2), a chemical absorption rate in mg/cm^2 surface area/hour/unit concentration is derived. Dermal absorption of inorganics is assumed to be negligible.

During wading, ingestion of sediment and surface water might also occur. The following assumptions were used:

- incidental ingestion of 100 or 50 mg/day sediment for a child or adult, respectively;
- incidental ingestion of 0.050 l/day surface water for both child and adult;
- an exposure duration of 2.6 hours/day;
- exposure frequency of 12 days/year (once per week for a period of 90 days);

- for wading, the lower half of the legs, from the knee down, is used to calculate skin surface area contacting water; a skin surface area of 350 and 550 cm² children and adults, respectively. For swimming, a skin surface area of 14850 and 18150 cm² for children and adults, respectively was used. This represents the average surface area for the entire body;

- an average body weight of 70 kg for adults, 45 kg for young children; and

- a RAF (relative absorption factor) of 1 for GI absorption of each constituent of concern.

Table 4.24 and 4.25 present exposure estimates for the recreational bathing scenario. Because the nature of the activity is assumed to be random, the constituent concentrations used for these calculations for sediment and surface water were based on the geometric mean (average case). Maximum values were not considered.

Ingestion of Sediment

Sediment ingestion was considered a possible exposure scenario for SW-16 during the dry period. The following assumptions were used in calculating the exposure concentrations:

- at this location, the exposed individual is a child (age 12 to 14). These exposures are pro-rated over a 70 year lifetime for carcinogens, but the averaging period is ignored for non-carcinogens;

- an exposure frequency of 30 days/year;

- the ingestion rate for soil is 100 mg/day; and

- a young child (12 to 14 years) weighs 45 kg.

Exposures estimated for the scenarios described here are given in Table 4.26. The constituent concentrations used for these calculations were the geometric mean (average case), and maximum (worst-case) concentrations for the sample taken from SW-16.

Fish Ingestion

Concentrations of constituents of concern in fish flesh were estimated by multiplying the surface-water concentrations by the appropriate bioconcentration factor. Assumptions used for estimating exposure by this pathway were:

- an average fish ingestion rate of 38 g/person/day and a maximum rate of 138 g/person/day;
- an exposure frequency of 48 meals/per year;
- ten percent of the fish diet is contributed by fish from the Hall's Brook Holding Area;
- an average body weight of 70 kg for adults, 45 kg for young children;
- a RAF (relative absorption factor) of 1 for GI absorption of each constituent of concern.

In the case of arsenic, it was further assumed that 10 percent of the total arsenic accumulating in the fish is in an inorganic form for which a cancer potency factor is available (USEPA, 1987, Table E-1). Exposure concentrations were based on mean surface-water concentrations. Exposure concentrations are presented in Table 4.27 and Table 4.28, while sample calculation spreadsheets are presented in Appendix G.

4.3.4 Risk Characterization

The purpose of the risk characterization is to quantify the degree of risk using information developed from the data evaluation/hazard identification steps and the toxicity and exposure assessment profiles. The term "risk" is further refined within this step to segregate carcinogenic from non-carcinogenic effects. Thus, the "risk" will be expressed as the incremental cancer risk due to the potential exposure to known or suspect carcinogens that may be present within the Study Area, and as the potential hazard due to non-cancer effects expressed as a ratio between the predicted exposure point concentration and the USEPA RfD (also known as a hazard quotient).

4.3.4.1 Results of Risk and Hazard Index Calculations

The potential impacts of the chemicals selected for the Site were estimated by calculating cancer risks for constituents of concern with known carcinogenic activity, and hazard quotients for constituents of concern that may exhibit short- or long-term systemic effects.

To evaluate cancer risk, the estimated exposure dose (calculated as described in Section 4.3.3) was multiplied by the appropriate cancer potency factor. The product obtained is the "risk" for that theoretical exposure, i.e. the increased probability that a person exposed as described would have of getting cancer as a result of that exposure. The tables included in this section

use scientific notation in reporting risk. For example, if the risk value were 1E-06, it would indicate a probability of 1×10^{-6}, or 1 extra chance in 1,000,000 of contracting cancer as a result of the exposure.

For noncarcinogenic constituents, it was assumed there is a toxic threshold (a dose below which no adverse effects will be seen), and the degree of hazard was expressed as the ratio of a standardized RfD to the exposure dose. This ratio is known as a hazard quotient. If the value is below one, then it is assumed that no risk is associated with the scenario. If the hazard quotient is above one, then an impact may be possible. Hazard quotients for compounds that have similar toxic mechanisms and/or effects may be treated in an additive fashion, expressed as a cumulative hazard index.

In the present risk assessment, cancer risks and hazard quotients were calculated for the exposure doses associated with exposure to media containing the maximum detected concentrations of constituents of concern, or as exposure to media at the geometric mean concentration (calculated from all data, using one half the detection limit as a concentration where non-detect was reported). Calculations were made for each individual chemical, as well as for the additive risks of exposure to mixtures.

As previously mentioned, hazard quotients are not usually added unless there is reason to believe the toxic action of different chemicals are similar and additive. In the results presented here, hazard quotients are added (to obtain a hazard index) for all chemicals only as a rough screen of potential impact on noncarcinogenic compounds. When the hazard index falls below one, there is a very low likelihood of impact. When the hazard index is above one, further analyses may be performed to determine if constituents of concern are likely to be additive in their toxic effects.

Ingestion and Household Use of Ground Water

Table 4.29 summarizes the estimated risks from a "worst-case" exposure to chemicals (i.e., if an individual were to use ground water near the Site as a sole source for drinking and other domestic uses). These risks have been calculated for average and maximum detected concentrations of chemicals in ground water except for arsenic. Analyses have shown arsenic species in ground water to be approximately 89 percent organic (MMAA and DMAA acids).

These compounds have not been shown to be carcinogenic (personal communication, Robert McGaughy, USEPA Carcinogen Assessment Group). Therefore, only 11 percent of the estimated exposure was applied to the cancer risk estimate. Total arsenic exposure was used for calculation of the hazard quotient.

Cancer risks for the water ingestion and household use scenario ranged from approximately 6.0×10^{-5} to 4.9×10^{-3}, for average and maximum concentrations, respectively. Benzene contributes the greatest portion of the risk in the calculations utilizing the maximum ground-water concentrations while arsenic contributes the greatest risk at average concentration. 1,1-Dichloroethene also contributes a portion of the risk, primarily from inhalation during showering.

Cancer risks were also calculated for a more reasonable (although still less feasible) scenario where an industrial worker might consume water from a well located downgradient from the Site (Appendix G). Cancer risks ranged from 9.1×10^{-6} for the average concentration, to 5.6×10^{-4} for the contribution of each well at which maximum concentrations were recorded. Risks under this exposure scenario represent at least a ten-fold decrease from those estimated for the domestic use scenario.

Hazard quotients for all metals, except antimony, arsenic, barium, cadmium, lead and zinc were less than 1 when calculated using maximum observed concentrations, indicating as low likelihood of health impact for all constituents but these. The only hazard quotient above 1 for average concentrations is antimony. The hazard index (all hazard quotients summed) is 6.3 due primarily to antimony, plus significant contributions of below unity hazard indices from arsenic, cadmium and lead. It is questionable, however, if the toxicity of these compounds should be assumed additive. The toxic effect of antimony is non-specific (reduced lifespan in experimental animals), while the toxic effects considered for arsenic, lead, and cadmium are ketosis of the skin, effects on blood forming elements, and kidney effects, respectively. Thus, the target organ toxicity is different in each case. It is known that lead also affects the kidney, but the literature indicates that neither arsenic nor lead seem to interact with cadmium to produce increased renal toxicity (Buchet, *et al.*, 1981; Mahaffey and Fowler, 1977).

Recreational Bathing - Wading or Swimming

Tables 4.30 and 4.31 list the estimated cancer risks and hazard quotients for exposure to constituents of concern in surface water and sediments, if one were to wade regularly in the Lower South Pond. The risks for this scenario were 1.3×10^{-5} and 8.6×10^{-6} total carcinogenic risk for the children and adults, respectively. All hazard quotients were less than 1 for the exposure scenario, as was the additive hazard index, indicating that this level of exposure would be unlikely to cause a health impact.

A similar exposure scenario was evaluated for Hall's Brook Holding Area, should trespassers or residents of the industrial park surrounding the water body make frequent use of this pond. Hall's Brook Holding Area is deeper than Lower South Pond, so the exposure scenario considered swimming (i.e., complete immersion) rather than wading. Tables 4.32 and 4-33 show cancer risks and hazard quotients for this scenario. Total cancer risks for children and adults, respectively, were calculated to be 6.2×10^{-5} and 4.0×10^{-5}. A majority of this risk is derived from arsenic and the potentially carcinogenic PAH present in sediment. No hazard quotient is greater than 1 (nor is the additive hazard index) indicating a low likelihood of impact from non-carcinogenic substances for this scenario.

It is notable that the operations at the facilities near Hall's Brook Holding Area seem likely to discourage the types of activities, such as children visiting, that promote relatively frequent exposure analyzed in this scenario. Thus, the exposure scenario may be characterized as worst-case.

Ingestion of Sediment

Table 4.34 summarizes the cancer risk estimates for exposure via ingestion of chemicals in sediments using the analytical results at sampling location SW-16. For the present scenario, in which children make occasional contact with sediment, the calculated risk is 4×10^{-5}. A majority of the total risk reported for this pathway comes from arsenic; the next largest proportion of total risk, from carcinogenic PAH, is an order of magnitude lower than the arsenic risk. The additive hazard index does not exceed one.

Fish Ingestion

Tables 4.35 and 4.36 give cancer risk and hazard quotient values for exposure to chemicals that might be available to fish inhabiting the Hall's Brook Holding Area. As mentioned in the exposure assessment, this impoundment is fished by individuals, primarily those employed by surrounding industries. Total cancer risk values ranged from 1.0×10^{-6} to 3.6×10^{-6}, depending on the assumption used for the amount of fish ingested. The overwhelming portion of the total cancer risk comes from arsenic; no other compound contributes more than 1/100 the risk produced by arsenic in this scenario. The hazard quotient is less than one, indicating low likelihood of a health impact from other toxic chemicals.

4.3.4.2 Uncertainty Associated with the Risk Assessment

There will always be uncertainty associated with risk estimates as a result of the limitations imposed upon the process (e.g. development of worst-case scenarios, use of assumptions). The following discussion identifies the uncertainties associated with variables used for risk calculation in this health risk assessment, and notes the effect that the uncertainty may have on the estimate. The discussion is arbitrarily divided into two parts, toxicity information and exposure information.

Toxicity Information

Toxicity data for health risk assessment is obtained from observations of toxic effects in humans accidentally exposed to chemicals, or from observations of deliberately dosed experimental animals. On a chemical-by-chemical basis, there is variability in the confidence which can be placed in the experimental results, based on the quality of the experimental protocol, the number of species and individuals utilized, whether the results were independently reproduced, etc. A discussion of the weight-of-evidence system for ranking potential human carcinogens, which takes many of these issues into account, was presented in the Toxicity Assessment section of this report. Weight-of-evidence rankings for the constituents of concern are given in Table 4.18 and elsewhere in the report.

The findings of this risk assessment indicate that, while several chemicals have been detected at the Site, and contribute to the overall health risk, arsenic is the chemical of primary

concern. Therefore, the uncertainties associated with toxicity assessment for arsenic are worthy of consideration. This topic was reviewed in a special report from USEPA in 1987 (USEPA, 1987).

There is a fairly strong association between inhaled arsenic and lung cancer. While there are indications that skin cancers may result from the ingestion of arsenic, there are also reasons to believe that certain modifying factors may need to be considered in doing risk assessment on cancer from oral exposure to arsenic.

As discussed in the toxicity profile (Appendix G), the evidence that arsenic causes cancer by the oral route comes primarily from a large epidemiology study of a Taiwanese population consuming ground water containing high natural levels of inorganic arsenic. Exposed individuals had a three to four fold higher risk of a particular type of skin cancer relative to controls. Some uncertainty concerning the finding is derived from the fact that other chemicals were also present in drinking water. The independent or interactive effect of the chemicals with arsenic is unknown. Additionally, the studied population had a diet generally different than the typical American diet; a low protein intake that might alter the ability of the body to detoxify and eliminate arsenic. On the other hand, while most cancer potency factors are the upper 95 percent confidence levels on the slope, the review by USEPA resulted in a decreased estimate of cancer potency than what had previously been believed. Nonetheless, the toxicity values developed were still considered duly conservative and more likely than not to overestimate risk. The potency factor for arsenic is a maximum likelihood estimate (this seems reasonable given that the toxicity was observed in humans rather than experimental animals).

Dietary differences not withstanding, the findings of the Taiwanese study are applicable to only inorganic forms of arsenic. At the Site, both DMAA and MMAA or have been identified in ground water and represent a large fraction of the total arsenic present (Appendix G). There is no available evidence to suggest that either form is carcinogenic in humans or laboratory animals.

On a more general basis, much of the uncertainty in toxicity information arises from three factors in experimental toxicity data that are not well known.

1. Is toxicity observed in animals representative of what may occur in man?

    If toxic effects occur in animals that would not occur in man, using experimental data in the development of a risk assessment the impact will be overestimated (i.e., estimating the incidence of a toxic effect, when its true likelihood is zero). However, relying on information from animals when humans suffer different effects altogether will cause underestimates of impact.

    USEPA's response to this uncertainty is to assume effects seen in animals can be extrapolated to man and, further, to assume, failing evidence to the contrary, that humans are more sensitive than animals to the observed effects. Thus, in setting an RfD, a no-effect level is often divided by ten to account for species to species extrapolation. Dourson and Stara (1983) report that this practice seems to be substantiated by scientific evidence as protective. In the case of cancer dose response, USEPA assumes that relative sensitivity to a toxic effect is related to surface area of the body. The practical result of this assumption is that dose response data is generated as if humans were 13 times more sensitive than mice and five to six times more sensitive than rats.

2. Can toxicity observed in a small group of animals or humans be extrapolated to a large population of people that may be diverse in their susceptibility to the toxic effects of a chemical?

    It is clear that humans vary in their response to chemicals. Even if extreme sensitivity is rare, in a large population there are always individuals who respond to lower doses than the "average" individual. USEPA's response to this variability is to generally require a ten fold reduction in the no-effect level (or a 100-fold reduction in the lowest dose observed to cause an effect) to arrive at an RfD.

3. Can one extrapolate effects seen at high doses to possible effects at low doses? How should the extrapolation be carried out?

Determining how one should extrapolate to low dose effects is among the least certain aspects of health risk assessment.

As previously mentioned, the mechanism by which certain chemicals cause cancer suggest that there would be no dose of these chemicals that was without some risk of producing cancer. If this were the case, and a threshold were presumed, underestimates of risk would occur. Thus, the prudent assumption used for most risk assessments is that the no-threshold condition exists for all carcinogens. USEPA uses this assumption and employs models for dose-responsiveness that are among the more conservative for estimating low dose response. Additionally, for data utilizing the linearized multistage model (as noted in the toxicity profiles presented in Appendix G), the upper 95 percent confidence interval on the possible slope of the line fit through the data is used. This approach makes it much more likely than not that the risk is overestimated using the cancer potency factors provided by USEPA.

Exposure Assessment

Uncertainties in the exposure assessment may be broken into the chemical data used for assessment and assumptions concerning the activities of individuals that promote exposure.

Chemical data may be uncertain due to limitations of the analytical technique, decreased precision or accuracy due lack of proper quality control procedures in the field or the laboratory, and increased variability due to human error. Laboratory data may indicate a value that is higher or lower than the true concentration, leading to overestimates or underestimates, respectively, of exposure. Underestimates or overestimates due to variance in chemical data or calculation errors are probably equally likely. The variability expected in chemical data (less than 50 percent) is relatively small in comparison to other uncertainties associated with the risk assessment.

Chemical data where concentrations are below the detection limit for the analytical method present a larger uncertainty. Chemicals may be present at concentrations just below the detection limit or may be absent resulting in no apparent difference. Overestimates or underestimates of exposure may occur, depending on the approach for the use of non-detected values in the risk assessment. Assuming a chemical is present (at the detection limit or some fraction of the detection limit) would overestimate exposure if the true value were lower, while assuming not detected was equivalent to zero when some chemical was actually present would underestimate exposure. The approach used in this risk assessment was suggested by USEPA Region I and represents a method intermediate to those described above.

When a chemical was not detected in any sample, it was eliminated from consideration (i.e., treated as if the concentration were zero). This leads to estimates that are equal to or less than the true exposure. Where chemicals were detected in some samples, but not others, the non-detects were treated as if a concentration equal to one half the detection limit were present. The may lead to underestimates or overestimates. When a "trace" of compound was reported, because it was below the limit of detection it was treated as if it were present in an amount equal to one half the detection limit. This may lead to underestimates or overestimates of exposure. The data base used for this risk assessment included data that was validated as "qualitative", i.e. there is a fair probability that the value, based on any number of reasons (e.g. exceedence of holding time or sample recovery) may not represent the true concentration.

Chemical data are obtained from samples taken at the Site, and there is always the question as to whether the samples are representative of the Site (or exposure location) as a whole. Sampling designs devised to determine the overall nature and extent (e.g. using a predetermined grid) may underestimate the risk if specific locations where there is increased probability for exposure are undersampled (although the likelihood of exposure occurring in any given area must be known to truly characterize this uncertainty). On the other hand, biased sampling designs, intended to identify "hot spots" based on visual observation, may tend to overestimate risks. The use of maximum and average concentrations for the media

of concern, helps to make it more likely than not, that the theoretical exposure is overestimated rather than underestimated. In the case of biased sampling regimens, where sampling was done in "zones of opportunity," use of the data is more likely to overestimate than underestimate the general condition of the Site.

For many of the activities that promote exposure to chemicals there is variance among the population in the extent to which the activity occurs. For involuntary activities (e.g. breathing, fluid intake) the variance is controlled mostly by physical size and activity and is often fairly well understood. For more esoteric activities, variance may be larger, and related to personal preferences. Examples of this type of exposure parameter are soil ingestion, which would be expected to be more extensive in children and individuals spending greater periods of time outdoors, or ingestion rates for foods, such as fish, which are highly variable by region, culture, and among individuals. Use of different values for these variables lead to an estimate of exposure that is relevant to some portion of the population, but not others. That is, unlike the variance in chemistry data that causes an estimate to be different from a "true" value, changes in this type of exposure value causes one to, for instance, accurately estimate an exposure for an "average" individual, but underestimate the exposure to people who practice the exposure-promoting activity to a greater than average extent. USEPA favors protecting a large portion of the population by using some exposure variables that are above the 90th percentiles for confidence. That is, USEPA's response to the uncertainty of exposure parameters is to consider a reasonable maximal exposure.

It is notable that a large portion of the population may be protected in the face of uncertainty even if only a few of the exposure variables are of high or even median confidence because, for all exposure variables that are independent of each other, the probability of the overall exposure is a multiple of each confidence level for each individual variable. An everyday illustration of this principle of probability is that while obtaining "heads" on a coin flip is a very likely event (1 chance in 2, or 0.5), the probability of obtaining heads on each of 10 coin flips is relatively rare (approximately 1 in 1000) and is calculated by multiplying the probabilities of the individual events (.5 ten times, or $.5^{10} = 0.00098$).

It should be noted that, in this example, the variables are treated as though all are random events. However, the "situations" that promote exposure of a certain type, such things as the likelihood certain locations at the Site would be used for the described purpose (e.g. fishing, swimming) or the probability that the water unit underlying the Site would be redeveloped as a drinking water source, are dependent on non-random matters such as land use regulations or the economy.

In summary, much of the information required for risk assessment is uncertain. In the face of uncertainty, conservative assumptions are typically used, and these assumptions are compounded by the multiplicative nature of the assessment. Thus, unless some uncertain parameter has been substantially underestimated the assessment is more likely to overestimate than underestimate risk. If the confidence values for toxicity and exposure parameters could be calculated in a precise manner, in theory, the probability of an exposure scenario and toxicity value could be multiplied by the health risk estimate to arrive at an overall probability of a health impact. For the time being, these data are treated qualitatively using such descriptors as "reasonable maximal exposure" and "worst case."

4.3.5 Conclusions

Substantial difference exists in the potential health impacts of the Site, depending on the particular exposure scenario considered. Differences also exist in the certainty associated with the scenarios and the level of conservatism applied to each analysis.

Five exposure scenarios were analyzed that apply to present or potential future use of the property. Of these analyses, only one, ingestion and household use of drinking water from a domestic source, produced estimated risks of greater than 1 in 100,000. The estimated risks for this improbable exposure scenario ranged from $10^{-4}/10^{-5}$ for average constituent concentrations to 10^{-3} for maximum constituent concentrations. Analysis of risks for a more reasonable exposure, such as consumption by an industrial worker, produced a lower range of risk estimates. As municipal water is available from other sources, both scenarios are considered a potential future use case.

Estimated risk levels for uses of surface-water bodies such as fishing, swimming, and sediment contact ranged from 10^{-5} for swimming, wading, and ingestion of sediment to 10^{-6} for fish ingestion. The probability of such exposures occurring are, at present, very low.

Inspection of the results of this human health risk analysis reveals that, while several chemicals were observed in the various media, and contribute to the overall potential risk of the Site, arsenic is the primary constituent of concern for the scenarios investigated. The mechanism responsible for mobility, and the evaluation of the different species that may be present in ground water, is currently under investigation.

Looking at the Site-related risks in a broader context, the implementation of the remedy (currently at the 60 percent design stage) will reduce both the concentration of constituents of concern in ground water and the potential for downgradient exposure. Thus, the major contribution to the total risk at the Site will be, for the most part, eliminated.

4.4 Ecological Assessment

An ecological assessment (EA) is a qualitative and/or quantitative appraisal of the actual or potential effects of a hazardous waste site on plants, wildlife and domesticated species (USEPA, 1989e). The approach utilized in conducting this assessment for the Site is discussed below.

4.4.1 Introduction

Typically, an EA is instituted using a phased approach. This document presents the results of the initial phase of the ecological assessment process for the Superfund Site, and was conducted as a part of the GSIP RI. The focus of GSIP RI was to address concerns outlined in Appendix H of the CD, which addresses migration of metals and volatile organic compounds in ground and surface water. Consequently, the focus of this assessment is on impacts to the aquatic community which is supported by the Aberjona River and associated tributaries and wetlands. Additionally, a considerable amount of information has also been developed through the PDI. Data developed through the PDI is intended to supplement remedial activities at the Site. For completeness, this EA uses data sets from both the GSIP RI and the PDI.

4.4.2 Objectives

The objectives of the ecological assessment are as follows:

- identify the types of habitats, organisms, and communities on or around the Site;
- evaluate the nature and extent of organic and inorganic compounds at the Site; and
- determine if there is an adverse (or beneficial) relationship between 1 and 2.

Guidance used to achieve these objectives is cited in the references given at the end of this document (USEPA, 1973, 1982, 1986, 1987, 1989a,b,e,f; ORNL, 1986; APHA, 1989)

4.4.3 Scope of the Investigation

The field survey was conducted over a two week period during May of 1990. Biological sampling stations (designated "BS") were located 20 to 50 meters upstream of each surface water station (designated "SW") required by the GSIP RI Work Plan (Plate 1) Additional sampling stations (BS-18 through BS-26) were selected upstream of the Site to serve as "reference" stations for comparison of benthic macroinvertebrate communities. Samples of sediment or surface water were not taken at these stations, although physical measurements (pH, D.O., temperature, conductivity) were performed.

4.4.4 Evaluation of Site Characteristics

Surface-water hydrology, aquatic habitats, and site impacts are discussed in the following sections.

4.4.4.1 Watershed/Hydrology

The headwaters of the Aberjona River start in Reading, Massachusetts and flow southwest, through several wooded wetlands, under Route 93, and onto the Site where the River changes course toward a more southerly direction. The principal tributary is Hall's Brook, which drains the northwest section of Woburn, eventually discharging into the Hall's Brook Holding Area. Onsite, the Aberjona is also fed by several small wetlands and tributaries (WMS, 1986), including the combined flow from the Lower South Pond and Phillips Pond. The Aberjona meets the southern tip of Hall's Brook Holding Area just north of Route 128, and flows south

until it meets Upper Mystic Lake in Winchester approximately 4.5 miles downstream of Route 128. Based on information from the Massachusetts Division of Water Pollution Control (314 CMR 4.0 - 4.06), the area of the Aberjona River north of Route 128 represents less than 10 percent of the Mystic River Basin watershed.

The water quality of this section of the river is classified as B, meaning that these waters are designated "as a habitat for fish, other aquatic life, and wildlife, and for primary and secondary contact recreation" (CMR 314 4.05).

Several field investigations were performed, as part of the GSIP RI, to determine the contributions of the various tributaries to the total streamflow of the Aberjona (see Section 3.3). Because this portion of the Aberjona is a headwater stream, the size of the stream and thus the discharge rate generally increase as one moves from north to south.

For the purposes of the EA, the contribution of each tributary was assessed relative to the total flow at SW-14 during late summer, which was considered 100 percent (Table 4.37). The Lower South Pond and the North Branch of the Aberjona (north of SW-17) account for less than 12 percent of the total discharge, while Hall's Brook and Hall's Brook Holding Area account for approximately 70 percent of the total (the flow from the Hall's Brook Holding Area was estimated by subtracting the contribution from SW-10 and SW-12 from the total flow).

A more in-depth analysis of the surface water hydrology at the Site is provided in Section 3.3.

4.4.4.2 Habitat

A preliminary assessment of the aquatic habitat was conducted by Wetland Management Specialists (Section 4.1.1.). For assessment of macroinvertebrates, habitat was segregated into two general categories, lentic (standing water) and lotic (flowing water).

The initial Site reconnaissance confirmed many of the observations made in the former wetlands evaluation. Maps obtained from the Soil Conservation Service (Acton, MA) indicate that almost all of the land area associated with the industrial park is classified as "udorthents" (fill). It is clear that many of the wetlands have been altered and that most of the Aberjona

River (within the Study Area) has been channelized and/or culverted, with rip-rap placed for bank stabilization. Vegetation in these areas is sparse, which restricts canopy cover and precludes input of organic matter (e.g. leaves) necessary to support a robust community of benthic macroinvertebrates. Stream beds are narrow, shallow, and generally lacking in substrate (e.g. cobble) suitable for colonization by periphyton and aquatic insects.

Based on the above observations, it was concluded that much of the available stream habitat could be classified as "disturbed" and would be considered less than adequate to support a diverse community of fish or benthic macroinvertebrates.

4.4.4.3 Non-Site Related Impacts

Reconnaissance of upstream areas revealed considerable disturbance associated with suburban development. Sections of the North Branch of the Aberjona and Hall's Brook pass through residential property, receiving runoff from roads via storm drains. Downstream areas also receive obvious non-point source impacts. Large parking lots located within the industrial park (e.g. Woburn Mall, Digital), as well as fairly long segments of Routes 93 and 128, discharge stormwater into the Aberjona River. Aquatic communities may be adversely affected by the presence of toxic constituents (e.g. salt, oil, metals) present in the runoff. A complete map, detailing location of storm drains and outfalls into the Aberjona and its tributaries, is presented in Section 3.3 (Plate 14).

Based on available information, the Woburn Sanitary Landfill appears to be discharging ground water into the New Boston Street Drainway, which eventually empties into Hall's Brook. Analyses of ground-water samples taken downgradient of the landfill (see Section 3.2) performed for the City of Woburn reveal the presence of constituents of concern (e.g. lead, manganese, zinc, VOCs). These compounds may potentially affect aquatic communities located downstream of this drainage area.

Finally, the deposition of particulate from diesel and automobile exhaust, contributed by the large volume of traffic (i.e., Route 93 and 128; industrial park activities), may contribute to the burden of lead and PAH compounds in soil and sediment on and around the Site.

4.4.4.4 Site-Related Impacts

Site-related impacts have already been reviewed (see Section 1.2). Based on this information and the preliminary Site evaluation, the following were identified as sources of constituents of concern for aquatic wildlife:

- arsenic pit (Lower South Pond);
- hide pile leachate (Lower South Pond); and
- metals in surface water, sediment, or ground water (see Section 4.4.6, Hazard Evaluation).

4.4.5 Field Survey

The purpose of the Field Survey was to collect fish and benthic macroinvertebrates and to assess the habitat at each preselected sampling station.

Fish were sampled qualitatively, using a gill net in deep water (greater than 5 feet) and a portable backpack electroshocker in shallower waters. For lentic habitats, macroinvertebrates were sampled quantitatively using a Petite Ponar Dredge or Ekman Grab Sampler. For lotic habitats, macroinvertebrate sampling was performed using a Surber Sampler (a D-Net was used if the flow rate was not sufficient to gather an adequate Surber sample).

Measurement of water quality parameters (D.O., pH, temperature, and conductivity) were taken at each biological sampling station. These values are presented in Table 4.38. These measurements generally agree with those taken during the GSIP RI surface-water investigation and meet Massachusetts Surface Water Quality Standards for Class B waters (314 CMR 4.0).

Evaluation of habitat was performed according to USEPA guidance (USEPA, 1989f). Each parameter was judged separately by two field biologists with experience in Rapid Bioassessment Protocols. Scores from each person were then averaged and tabulated. A complete summary of the field data is presented in Appendix G.

4.4.6 Hazard Evaluation

Methods for the development of the hazard evaluation (HE) were taken from the USEPA guidance for the assessment of ecological impacts (USEPA, 1989b; USEPA, 1989e). This guidance suggests that all constituents of concern be addressed, but that certain criteria be

used to determine whether a particular constituent be included or omitted from the risk assessment. (This process is necessary to reduce the complexity of the document and to focus on compounds that are likely to present the highest potential for risk.) These criteria include the toxicity of the compound, frequency of detection, background concentration, environmental persistence, mobility, fate and transport processes, and the quality of the data base. State and Federal standards and criteria were also addressed.

In addition to these criteria, it is important to recognize that the ecological impact of a chemical is directly related to the potential for an environmental receptor to be exposed to it. Thus, the location of each constituent is assigned weight in the HE process.

Finally, the professional opinion of an experienced toxicologist was used to identify inconsistencies in the data base, evaluate and compare available criteria, and to make the final choice of "indicator chemicals" to be used in the risk assessment.

4.4.6.1 Data Evaluation

The first step in a human health risk assessment or ecological evaluation is the tabulation and statistical evaluation of the chemical and physical data gathered during field investigations. Because this initial data evaluation step is similar for both types of "risk assessments" (USEPA, 1989a, c, e), they are combined in the present report.

4.4.6.2 Methodology

Tables 4.15, 4.16, and 4.17 identify classes of compounds (metals, VOCs, and SVOCs, respectively) and the media in which these compounds were detected. Criteria for the elimination of each compound from the HE are listed for each constituent and each medium.

It is known that natural background concentrations of metals in surface waters and sediments, with respect to the mean value, can generally vary from two fold to five fold (Shacklette and Boerngen, 1984; Baudo, et al. 2, 1990). Consequently, with regard to evaluating the metals based on the Site area/reference area mean ratios, an arbitrary cutoff value of 2 was chosen as a plausible threshold criteria.

4.4.6.3 Surface Water

<u>Metals</u>

Of the metals detected in surface water, only antimony, arsenic, copper, chromium, lead, manganese, and zinc have the potential to cause toxicity. Aluminum, barium, calcium, iron, magnesium, potassium, and sodium were not considered in this assessment since they are virtually non-toxic at the levels seen in surface water at the Site.

Beryllium, cadmium, mercury, nickel, selenium, thallium, tin, and vanadium were not detected and hence are not considered in this EA. Antimony, cobalt, and silver were detected infrequently and had mean site/relevance ratios close to 1 and were eliminated from consideration in the EA.

The following metals were considered indicator compounds in surface water for inclusion in the EA portion of the risk assessment:

- Arsenic
- Chromium
- Copper
- Lead
- Manganese
- Zinc

<u>Volatile Organic Compounds</u>

Table 4.16 lists criteria used to assist in the constituent selection process for VOCs in surface water. Generally, all VOCs concentrations are well below concentrations known to cause acute or chronic effects in aquatic organisms (which are in the low mg/L range). Consequently, VOCs will not be considered as constituents of concern in the EA.

<u>Semi-Volatile Organic Compounds</u>

Table 4.16 lists criteria used in the constituent selection process for SVOCs in surface water. These compounds were also detected infrequently and at concentrations considered well below those known to be of concern to aquatic flora and fauna.

4.4.6.4 Sediment

<u>Metals</u>

Table 4.15 lists criteria used in the constituent selection process for metals in sediment. Of the metals detected in sediment, antimony, arsenic, barium, beryllium, cadmium, chromium, copper, lead, mercury, manganese, nickel, selenium, silver, thallium, and zinc have the greatest potential to induce toxicity. Aluminum, calcium, cobalt, iron, magnesium, potassium, sodium, tin, and vanadium were not considered since they are virtually non-toxic at the levels seen in sediment at the Site.

There is only limited information available concerning sediment quality for beryllium, selenium, and thallium. The Site/reference area ratio for all three was below 3.0 (Table 4.6) and the distribution of the values was close (Table G-1B2) to the mean. Past studies have shown that these metals are not predominant at the Site, therefore the presence of these compounds at the Site would probably not present a problem for fish and benthic macroinvertebrates in sediments.

The Site means for manganese, mercury, and nickel all fall below concentrations cited as "non-polluted" using sediment criteria gathered by several authors (Baudo, *et al.*, 1990). Mean mercury, nickel, and silver sediment concentrations also fall within a range of concentrations typical of average *soil* concentrations for the United States (Shacklette and Boerngen, 1984). Speciation data for mercury, conducted by Radian Corporation, indicate that no significant concentrations of organo-mercurials exist in surface water or sediment. Barium is typically present in sediment complexed as the sulfate or carbonate, which is insoluble and virtually non-toxic (USEPA, 1986). Given the above observations, it was decided that the elimination of barium, manganese, mercury, nickel, and silver from consideration in EA was justified.

Consequently, the remaining constituents will be considered as indicator chemicals for the evaluation of the metals in sediment:

- Antimony
- Arsenic
- Cadmium

- Chromium
- Copper
- Lead
- Zinc

Volatile Organic Compounds

Sediment quality criteria only exist for VOCs. Ambient Water Quality Criteria (AWQC; USEPA, 1986) suggest that aquatic organisms are not affected by most VOCs until water concentrations reach 0.5 to 1.0 mg/L or higher. Additionally, it is known that VOCs will usually partition to the organic phase of the sediment, (directly proportional to the percentage of TOC). This appears to be the case at the Site, where sediment concentrations of VOCs correlate fairly well with sediment concentrations of total organic carbons (TOC) (e.g. SW-6 and SW-9). VOCs were not considered as constituents of concern in this EA for the following reasons:

- the concentrations of VOCs in sediment, with the exception of the Hall's Brook Holding Area, are unremarkable;
- the concentrations of TOC are relatively high (greater than 5 percent); and
- no sediment quality criteria data exist for these compounds.

Semi-Volatile Organic Compounds

Table 4.16 lists criteria used in selection of SVOCs as constituents of concern in sediment. Benzoic acid, butylbenzylphthalate, dibenzofuran, 3,3-dichlorobenzidine, 2,4-dinitrotoluene, and N-nitrosodiphenylamine were detected infrequently (1 of 17 samples) and criteria are not available for assessing the toxicity of the compounds to aquatic organisms. Toxicity information is not available for bis(2-ethylhexyl)phthalate, diethylphthalate, acenaphthylene, benzo(b)fluoranthene, benzo(g,h,i)perylene, benzo(k)fluoranthene, and indeno(1,2,3-cd)pyrene; these compounds were not selected as constituents of concern. However, information is available for Total PAH, and the aforementioned PAH compounds were considered in evaluation of total PAH toxicity.

The following compounds were selected for evaluation in the EA:

- Anthracene
- Benzo(a)anthracene

- Benzo(a)pyrene
- Chrysene
- Dibenzo(a,h)anthracene
- Fluoranthene
- Phenanthrene
- Pyrene
- Total PAH

4.4.6.5 Ground Water

Two locations were identified where discharge of ground water to surface water was evaluated relative to the potential effects on aquatic receptors. The first location was used to assess discharge of ground water to SW-17 (East Central Hide Pile). The second will be used to assess the discharge of ground water into the Hall's Brook Holding Area from the north, (i.e., observation wells OW-12, OW-13, OW-17 and OW-18).

Metals

Based on current data, antimony, cadmium, chromium, lead, mercury, and nickel have little propensity to move in ground water and thus will not be considered as a potential threat to surface-water receptors. Barium is found in all wells but would be considered to be virtually non-toxic to aquatic organisms at the present concentrations.

Given their current mobility and toxicity, the potential effects of the following metals on aquatic receptors were evaluated:

- Arsenic
- Copper
- Zinc

Volatile Organic Compounds

Based on their current mobility and toxicity, the following VOCs were evaluated:

- Benzene
- Toluene

Semi-Volatile Organic Compounds

SVOCs were found infrequently in ground water. However, most of the maximum values detected were measured at OW-16, which is close to a segment of the Aberjona that is known to be gaining water through ground-water discharge (SW-17). Therefore, only phenol will be considered in the evaluation. Methylphenol(s) or benzoic acid will not be evaluated, as AWQC are not available for these compounds.

4.4.7 Types and Numbers of Aquatic Receptors

Table 4.39 summarizes the species and number of fish collected at each biological sampling station. No endangered or threatened species were caught or observed on-site or off-site and none are expected to occur within the Study Area. All of the individuals identified are "abundantly represented" in the state of Massachusetts (Halliwell, 1984).

Based on the yield from electroshocking, American eels were the dominant fish species in the Aberjona River. Golden shiners and Pumpkinseeds were caught or observed in all of the ponds sampled, with the exception of the unnamed pond east of the East Central Hide Pile (this pond was shallow (less than 2 ft) and did not yield any fish). Pumpkinseeds were the dominant fish in Lower and Upper South Pond. A complete list of wildlife in this area, based on observations by ESE, Wildlife Management Specialists, and Normandeau Associates, Inc. is presented in Table 4.40.

Table 4.41 presents a summary of macroinvertebrates collected at each biological sampling station, as well as the relative percent contribution of each family level (a complete record of the data base in presented in Table G-1D, Appendix G). Chironomids (midges) and oligochaetes (worms) were the dominant orders at most of the stations sampled. Aquatic invertebrates representing families that are more intolerant to environmental stress (e.g. mayflies [Ephemeroptera], stoneflies [Plecoptera], and caddisflies [Trichoptera], or EPT) were rare, if found at all.

4.4.8 Potential for Exposure

Most fish and macroinvertebrates have the ability to avoid adverse environments by active migration or by drifting. However, these movements may be limited in some habitats by physical constraints such as dams or seasonal fluctuation in water levels.

During periods of high flow, fish within the Aberjona River have relatively easy access to Phillips Pond, the unnamed pond east of the East Central Hide Pile, the Hall's Brook Holding Area, and Hall's Brook. However, the southern section of the Hall's Brook Holding Area is shallow and the vegetation is dense, which may restrict larger species of fish from the main holding area (adjacent to Digital) during dry periods when water levels may drop.

Fish within the Lower and Upper South Pond would only be able to migrate downstream, as the presence of an elevated culvert, which spills into SW-17 at a height of approximately 2 feet above the surface of the stream, precludes the possibility of fish migrating into the wetland.

4.4.9 Measurement endpoints

Endpoints calculated to assess the relative distribution and diversity of organisms include taxa richness, total abundance, evenness, Shannon-Weaver Diversity Index, EPT Index, Modified Family Biotic Index, and EPT/Chironomidae ratios.

Rapid Bioassessment Protocol II (RBP II) habitat scores were also calculated according to USEPA guidance (1989f). These scores take into consideration the various components of habitat that are conducive for a healthy aquatic community, e.g. type of substrate, stream flow, presence of riffles, channel morphology, erosion, and vegetative cover. Scores can range from 0 to 135, with higher scores being indicative of quality habitat.

Taxa richness is the total number of genera represented within each sample, while total abundance is simply the total number of individuals within each sample.

The modified Family Biotic Index (FBI) was originally developed for assessing how various macroinvertebrate species are able to withstand or "tolerate" organic pollution. The FBI is calculated as:

$$FBI = \Sigma \frac{x_i \, t_i}{n}$$

where,

x_i = number of individuals within a taxon

t_i = tolerance value of a taxon

n = total number of organisms in the sample.

Tolerance values range from 0 to 10 for families and increase as water quality decreases. Thus, a higher FBI generally indicates an increase in the number and types of taxa that are tolerant of organic pollution.

The Shannon-Weaver Diversity Index is probably the most commonly used metric for assessing ecotoxicological effects. It is calculated as:

$$\text{Shannon-Weaver DiversityIndex} = -\Sigma \left(\frac{n_i}{N}\right) \text{Log}_2 \left(\frac{n_i}{N}\right)$$

where,

n_i = number of individuals per taxon and,

N = total number of individuals.

Concepts of species diversity and diversity indices have been well established in the literature (Boudou and Ribeyre, 1989). In communities exposed to environmental stress or with unfavorable habitat conditions, the indices are generally low (few taxa are present and there usually is dominance by one or more taxon). In contrast, communities which experience better water quality and a supporting habitat generally have indices that are relatively high (many taxa are present and their numbers are equally represented). In short, a higher species diversity generally indicates more favorable habitat and consistent water quality. Diversity indices below 2 generally indicate ecological stress and/or unsuitable habitat. Values between 2 and 3 suggest moderate stress and habitat suitability. Values of 3 or greater indicate stable environmental conditions and a healthy benthic community.

Evenness, which is a measure of how well each taxon is represented as a portion of the total taxa present, was also calculated because changes in this component can bias the results of the Shannon-Weaver Diversity Index (Boudou and Ribeyre, 1989), especially within depauperate communities. This metric is calculated as:

$$E = \frac{H}{Log_e}(H \text{ of } taxa)$$

where:

H = Shannon-Weaver Diversity Index.

Evenness can range from 0 to 1. Values that approach 1 indicate that all taxa are represented in near equal numbers, and that no single taxa is dominant.

Another endpoint that can be helpful in the evaluation of community structure is the ratio of various functional feeding groups (USEPA, 1989f). However, it was found that greater than 99 percent of all of the insects collected for this assessment fell into the category of filterers/collectors and that bioassessment scores generated from the use of this metric would be the similar for all stations.

4.4.10 Characterization of Impacts

In the evaluation of the chemical data, a "toxicity quotient" method was used to assess the relative impacts of each constituent of concern (ORNL, 1986). This is simply the ratio of the measured or expected environmental concentration to a "benchmark" concentration (e.g. AWQC or sediment quality criteria). If the ratio exceeds unity, there is an increased probability that the constituent of concern may exert an adverse effect on the aquatic community in the respective sampling area. However, due to the unique physical and chemical nature of each site, ratio values falling below 1 do not necessarily imply that an impact will not occur, nor does a value above 1 imply an adverse community response.

4.4.10.1 Surface Water

Metals

Toxicity quotients for metals in surface water were generated by dividing the "in-stream" water concentration for each metal by the respective AWQC. Table 4.42 presents the results of this exercise, performed for both dissolved and total samples.

For both total and dissolved metals, none of the stations exceeded the current AWQC. SW-6 and SW-15 exceeded unity for manganese, using a literature-derived toxicity benchmark as no criteria are currently available for this metal (Stubblefield and Patti, 1990). The waters at the Site can be classified as "moderately hard". Since criteria for chromium, copper, lead, and zinc are dependent on hardness (toxicity decreases as hardness increases) the chemistry of the surface water at the Site appears to afford some protection to the aquatic community.

Although AWQC are met, it has been shown that mixtures of metals with individual concentrations below that of the respective AWQC may still cause both acute and chronic effects in aquatic organisms (Spehar and Fiandt, 1986). To evaluate each sampling station with respect to the potential impacts from the mixture, each ratio was considered a "toxic unit" and summed (see Section 4.4.12 for discussion of uncertainty). The results indicate that, if adverse effects were to occur due to the combined effect of the metals, the stations with the greatest probability of adverse impact to the aquatic community are located in the New Boston Street and Hall's Brook drainage area (SW-6, SW-7, SW-9, SW-11, SW-13, SW-14, and SW-15).

4.4.10.2 Sediment

Metals

Toxicity quotients for metals in sediment were generated by dividing the sediment concentration for each metal by the respective Effects Range-Low (ER-L) and Effects Range-Medium (ER-M) described by Long and Morgan (1990). These values were derived by reviewing field studies that have correlated sediment concentrations of toxic compounds with adverse effects on the benthic community. The studies were then ranked in order of increasing criteria concentrations, with the 10th and 50th percentiles designated as the "Effects Range - Low" (ER-L) and "Effects Range - Median" (ER-M), respectively. The ER-L represents a concentration where subtle effects on the benthic may start to become evident, while the

ER-M generally represents a concentration above which effects may frequently be seen in the benthic community. It is important to note that sediment criteria have not yet been formally developed by USEPA and that these values were used for lack of any other available information. Also, many of the values were derived from marine studies and may not be suitable with respect to the evaluation of freshwater environs. Section 4.4.12 presents a discussion to the limitations of the use of these values.

Table 4.43 presents the toxicity quotients generated for assessment of metals in sediments. The selection of SW-1, SW-3, SW-4, and SW-8 for reference stations appears to have been appropriate, as the metal concentrations generally do not exceed concentrations considered unfavorable toward benthic invertebrates. As seen with surface water, stations close to the proximity of areas targeted for remediation (e.g. Hall's Brook Holding Area, Lower South Pond, and New Boston Street Drainway) exceeded NOAA sediment quality values, while metal concentrations decrease as one moves further downstream (e.g. SW-5, SW-12, SW-14). As discussed in Section 4.4.6.4, the sediment characteristics within the Hall's Brook Holding Area are unique in that they have a large percentage of fines and thus a greater concentration of metals per unit weight. This is primarily due to the fact that this wetland serves to decrease water velocity, allowing the finer suspended particulate to settle out. The wetlands, south of the holding area and north of the Woburn Mall, also serve to decrease surface-water flow, especially during the spring when water levels are high.

A correlation matrix (Appendix G) was constructed to determine the relationships between the various water quality parameters and measurement endpoints developed for the Site. This table shows that there are some statistically significant, positive correlations between most of the trace metals in sediment. After adjustment for normality and grain size, arsenic was found to correlate strongly ($r > 0.70$; $p = 0.001$) with chromium, copper, lead, and zinc. Aluminum, barium, calcium, cobalt, copper, iron, vanadium, and zinc were also found in proportion with most of the trace metals.

Volatile Organic Compounds

In general, VOCs are not environmentally persistent compounds and, as a class do not pose a significant threat to aquatic biota unless present at substantial concentrations (i.e., greater than 1 mg/kg). Maximum values of VOCs were found in sediment samples with relatively

high percentages of TOC, which allows even less of the constituent to become available to the organism and cause an effect. Therefore, VOCs were not considered in the evaluation of sediment quality at the Site.

Semi-Volatile Organic Compounds

Toxicity quotients, along with cited ER-L and ER-M values for PAH compounds, are presented in Table 4.44. As seen with VOCs, PAH compounds have a very strong affinity for organic matter, and stations with increased TOC saw a concomitant increase in PAH. It is important to note that, although toxicity quotient exceeded unity, the presence of large amounts of TOC may decrease bioavailability and consequently the risk to benthic infauna.

Unlike the metals, there is no trend in the data that suggests an identifiable source for the PAH compounds. However, it is not uncommon to see concentrations of PAH as high as 100 mg/kg or more in sediments that receive water from industrial areas (Neff, 1984). Likely sources include the MBTA railroad tracks (asphalt, treated railroad ties), drainage from paved areas, runoff containing petroleum products from trucking operations, and atmospheric deposition of diesel exhaust. It was also observed that the interior of the galvanized culverts are coated with a tar-like substance, which may contain high concentrations of PAH.

4.4.10.3 Ground Water

Based on conclusions of the ground-water studies (Section 3.0), it was determined that some constituents of concern in ground water may pose a risk to surface-water receptors through discharge from the aquifer. The contribution of each constituent from ground water to surface water was performed by:

- calculating a mean value, based on the concentration of each constituent in OW-12, OW-13, OW-17, and OW-19 for the Hall's Brook Holding Area, and OW-16 and OW-22 for the Aberjona River;

- calculating a net ground-water flux into the Hall's Brook Holding Area and the Aberjona River from available hydrologic data and an assumed cross-sectional area; and

- determining an "in-stream" concentration of each constituent of concern based on 1 and 2.

Once the "in-stream" concentration is known, it can be compared to available AWQC and a toxicity quotient can then be calculated. For the Aberjona River, future in-stream concentrations were estimated as the current mean ground-water concentration in the vicinity of the river. Inherent in this calculation are the assumptions that the ground water near the Aberjona is the source of chemicals in the stream, and low flow conditions exist in the stream such that dilution due to surface-water runoff is negligible.

For the Hall's Brook Holding Area two different methods were used to estimate future in-stream concentrations. Metals concentrations were assumed to equal current ground-water concentrations. This assumes that ground water discharging into the Hall's Brook Holding Area are the sources of in-stream metals and ignores dilution with surface runoff (Hall's Brook). The concentrations of benzene, toluene, and phenol were estimated as one-tenth of the current ground-water concentrations, based on dilution with low-flow surface-water discharge into the Hall's Brook Holding Area. This also assumes that the source of these organic constituents is ground water discharging into the Hall's Brook Holding Area.

Metals

Table 4.45 presents the current and expected in-stream concentrations for arsenic, copper, and zinc. The toxicity quotients are also presented, with criteria for copper and zinc based on an average hardness of 92.9 mg/L for the Hall's Brook Holding Area and 130 mg/L for the Aberjona River. All of the toxicity quotients fell below 1.0, indicating a low probability that an adverse impact to aquatic receptors would occur as a result of the contribution of metals from ground-water discharge.

Volatile Organic Compounds

Table 4.45 presents the current and expected in-stream concentrations for benzene and toluene. The toxicity quotients are also presented. All of the toxicity quotients fall below unity, indicating a low probability that an adverse impact to aquatic receptors would occur as a result of the contribution of VOCs from ground-water discharge.

<u>Semi-Volatile Organic Compounds</u>

Table 4.45 presents the current and expected in-stream concentrations for phenol. Calculated toxicity quotients fell below unity, indicating a low probability that an adverse impact to aquatic receptors would occur as a result of the contribution of SVOCs from ground-water discharge.

4.4.10.4 Fish

Sampling of fish was performed to determine if any sensitive, threatened, or endangered species exist at the Site. The types of fish collected range from "intermediate" to "tolerant" in their ability to withstand adverse environmental conditions (USEPA, 1989f). Also, an external and internal examination of some of the larger individuals collected showed no gross abnormalities (e.g. humpback) or pathological lesions (e.g. tumors). Photographs of individual fish sampled from each station are presented in Appendix G.

The hydrology of both the Lower and Upper South Pond is such that the waters get quite shallow and warm during the summer months, allowing only the more tolerant warm water species to survive. These ponds also have an abundant population of Eastern Painted and Common Snapping turtles (Eastern Painted turtles were also seen in the pond east of the East Central Hide Pile).

Although only one fish (a Golden shiner) was caught in the Hall's Brook Holding Area, several schools of Pumpkinseeds were observed at BS-13 during surface-water flow measurements. An interview with one person fishing this area revealed that adult Largemouth bass also inhabit the area. Phillips Pond is also fished on occasion and appears to support a healthy community of Largemouth bass.

American eels were caught as far north as BS-12 and BS-5, but were not collected. Pumpkinseeds were observed at BS-5 during surface-water flow measurements.

4.4.10.5 Macroinvertebrates

Measurement endpoints for each station sampled at the Site are presented in Table 4.46. The relative contribution of each family, as a percent of the total number per station, is presented in Table 4.41. Locations of biological sampling stations are illustrated in Plate 1.

Lentic habitats (ponds) were dominated almost exclusively by chironomids (midges) and oligochaetes (worms) which prefer standing or slow moving water and muddy substrate. Because of depth, location, and type of habitat, Phillips Pond and the deep, ponded section of the Hall's Brook Holding Area did not have suitable reference stations for comparison. Both have been designed and constructed for flood control and have habitat typical of reservoirs (steep banks with poor vegetative interspersion and virtually no littoral zone).

The macroinvertebrate community for Phillips Pond, with an average depth of about 6 feet and a fairly consistent dissolved oxygen profile, might be considered typical of this type of environment. Based on the results of the physical, chemical, and biological data and observations taken during the field survey, it can be concluded that this pond does not appear to be adversely affected by the Site.

Samples taken from the Hall's Brook Holding Area indicate that this pond has a poor macroinvertebrate community. The Hall's Brook Holding Area, with an average depth of approximately 15 feet, had a stratified dissolved oxygen profile, with benthic conditions being virtually anoxic (less than 0.5 mg/kg D.O.). The mean percentage of TOC for the three stations within this area (SW-9, SW-11, SW-13) pond was 15 percent. This content of TOC (and fines) would tend to indicate the presence of a rich microbial community, consequently increasing the sediment oxygen demand and decreasing the oxygen content of the overlying water column. These conditions, in addition to the presence of constituents of concern (e.g. metals) that have migrated from the Site, may explain the virtual absence of benthic fauna at these stations.

Samples taken in ponds north of the Lower South Pond spillway (BS-22 and BS-23) can be compared against samples taken in the Lower South Pond (BS-1A, BS-1B, and BS-1C) and the pond west of the East Central Hide Pile (BS-24 and BS-25). Both upstream and downstream stations had similar numbers of taxa, although total abundance was lower for the downstream stations. With the exception of BS-24, Shannon-Weaver Diversity Indices were also lower for the downstream stations. Based on the data, it appears that there may be an impact on stations located in Lower South Pond. However, these results may be substrate-specific, as the stations in Lower South Pond were essentially dominated by chironomids, with few oligochaetes present.

Lotic habitats (flowing water) also had a large proportion of dipterans (flys and midges) and oligochaetes (worms) (Table 4.46). Reference stations located upstream of the Site (BS-3, BS-4, BS-22, BS-23, BS-18, BS-19, BS-20, BS-21) generally had a greater number of taxa than downstream stations (Table 4.41). Although pollution-sensitive families (EPT Index) were found more frequently upstream of the Site, their numbers were low at all stations. A large proportion of those that were found in appreciable numbers were identified as *Hydropsychidae*, which are known to be the more tolerant genera (i.e., able to withstand adverse conditions) of the caddisfly family (Clements, 1990).

Shannon-Weaver Diversity Indices were less than 2 for both upstream and downstream stations. This is most likely due to the fact that these small headwater streams are generally unproductive, the impact of non-point sources (e.g. pollutants in storm drain effluent, Plate 14) may prohibit the establishment of a healthy macroinvertebrate community, and the paucity of adequate habitat due to the restructuring of the stream channels. Relative to the reference stations, the diversity indices for BS-7, BS-15, and BS-17 were low, indicating a possible community disturbance.

The biological condition of most stations was also evaluated using the Rapid Bioassessment Criteria (Protocol II) developed by USEPA (USEPA, 1989f). Measurement endpoints (Table 4.46) are assigned a score, usually based on the ratio to a given reference site, and the scores for each station are added. The total score for the reference site is then compared to the total score for the non-reference site. The ratio of the total scores (non-reference/reference) is then calculated and the station is given the following classification based on the result:

- Non-impaired = greater than 79 percent of the reference score;
- Moderately impaired = 29 to 79 percent of the reference score; or
- Severely impaired = less than 21 percent of the reference score.

Results of this evaluation are presented in Table 4.47 (metrics are given in Table 4.46, percent contribution of dominant family was taken from Table 4.41: community loss indices were calculated directly from Table G-1D, Appendix G). Stations BS-7 and BS-15 were classified as "severely impaired", and stations BS-6 and BS-17 were near the lower range of "moderately impaired". The remaining stations were "moderately impaired".

These results are consistent with field observations, which indicate that the New Boston Street Drainway is severely stressed due to a heavy accumulation of iron precipitate. BS-2 and BS-7 also appear to be stressed due to the presence of leachate. One cannot, however, ignore the contribution of habitat. RBP II habitat scores are quite low for BS-2, BS-6, BS-7, BS-15, and BS-17, primarily due to the fact that the substrate in these areas is mud, the stream flow is less than 1 cfs, and the banks are unstable. Section 4.4.12 discusses limitations of this analysis.

A correlation (Pearson's) matrix of the log transformed data (adjusted for grain size) was constructed (Appendix G, Table G-1E) to evaluate specific relationships between measurement endpoints for the EA (BS-1 through BS-17 only) and chemical/physical parameters determined at each station. Habitat scores (which are generated qualitatively from field observations) were positively correlated with Shannon-Weaver Diversity Indices, indicating that an increase in the quality of the environment may generally increase the quality of the aquatic macroinvertebrate community. None of the potentially toxic metals in surface water showed any statistically significant correlations with functional endpoints.

Because of the low productivity of these streams and the predominance of the *Chironomidae* (midges), it was decided to further evaluate this family for the presence of tolerant and intolerant individuals. Table 4.48 presents the taxonomic evaluation and enumeration of the *Chironomidae* for four upstream (BS-4, BS-18, BS-19, and BS-21) and four downstream (BS-1C, BS-10, BS-14A, and BS-14B) stations. In terms of taxonomic range, the highest community diversity generally occurs above the discharge site, indicating a possible ecological impact.

Chironomus sp., which are commonly associated with standing or slow moving water, are found almost exclusively at BS-1C, probably reflecting suitable substrate and water flow conditions more than opportunistic habitation. *Cricotopus bicinctus*, a very adaptable and opportunistic species, appears in diverse, well-balanced communities but becomes dominant when various stresses restrict other, less tolerant species. This species is especially immune to metals and other toxic wastes. It has been shown to withstand electroplating wastes and crude oil and has a wide range of tolerances for pH, nutrients, and habitat type (Sheehan and Winner, 1984; USEPA, 1989f). This species is present at all stations, but tends to predominate below the Site, suggesting a Site-related stress that may be reducing or eliminating less tolerant species.

While counts were often small, and therefore preclude valid statistical analysis, it can be said that all taxa identified as sensitive to environmental stress (e.g. *Diamesa, Paratendipes sp.*) are restricted to above-site stations, whereas tolerant species are found both above and below the Site.

4.4.11 Conclusions

Based on the data and the above analysis, the following conclusions can be reached.

- No threatened or endangered species have been observed at the Industri-Plex Site.
- Fish species caught within the Study Area are commonly found in the waters of Massachusetts. The only species of economic importance is the Largemouth Bass. Internal and external examination of individual fish showed no gross abnormalities.
- Sensitive macroinvertebrate species are present upstream, but not downstream, of the Site. Although tolerant macroinvertebrate species are present at both upstream and downstream stations, the proportion of opportunistic species is greater downstream. The differences in the structure of these communities are most likely a result of Site-related impacts.
- Based on the chemical, physical, and biological data, the New Boston Street Drainway and the Hall's Brook Holding Area would, relative to the other stations, pose the greatest degree of risk to the aquatic community.

  - Impacts seen at BS-6, BS-7, and BS-15 (New Boston Street Drainway) may partly be a result of the presence of metals and metal precipitate (iron and manganese oxides), which are emanating from the Woburn Landfill. The habitat at these stations is also inadequate to support a healthy macroinvertebrate community.

  - Sampling stations BS-9, BS-11, and BS-13 (Hall's Brook Holding Area) are essentially depauperate communities. This could be a result of adverse environmental conditions (benthic anoxia, poor substrate), an adverse response to constituents of concern in the sediment, or a combination of both.

- Reduced leachate emanating from the East Hide Pile may be influencing the macroinvertebrate community at BS-17. Oxidation of the leachate contributes to the chemical oxygen demand observed at SW-2.

- As found in the RI/FS (Roux Associates, 1983;1984), antimony, beryllium, cadmium, cobalt, mercury, nickel, selenium, silver, tin, thallium, and vanadium were not detected in any surface-water samples. Chromium, copper, and lead were slightly soluble, being detected only in the total samples. Zinc appears to be the most soluble metal in surface water.

- Metal concentrations in surface water are well below the levels necessary to cause acute toxicity. If ecological effects are due to metals, it is probable that the impact would be the result of the combined, chronic effects of the commixture.

- Aquatic impacts as a result of VOCs in sediment and surface water are, in all likelihood, negligible. Concentrations of PAH's in sediment may pose some risk at SW-11, SW-12, SW-13, and SW-15.

- Based on current hydrologic data, no impacts to the aquatic community would be anticipated as a result of the influx of constituents of concern from ground water into surface water.

- Diversity indices were less than 2 for all biological sampling stations. This is partially due to the fact that small headwater streams are naturally unproductive (USEPA, 1989f). Putative, non-site related impacts, such as non-point source pollution (stormwater runoff from residential and industrial areas, Route 93 and 128), the alteration of the habitat by diking and channelization, and lack of adequate benthic substrate and input of coarse particulate organic matter, may also contribute to the poor insect diversity seen at both upstream and downstream stations.

4.4.12 Significance of Impacts to the Water Resource

Based upon the information developed in this study and data obtained from past investigations (WMS, 1986; Normandeau, 1990), this section evaluates the Study Area on a broader context and describes how it relates to the surface-water resource and its intended use.

Aberjona River

It appears that much of the intended use of the Aberjona River (within the Study Area), as it exists today, is to control the flow and direction of the river to accommodate the requirements of the industrial park. Within the Study Area, much of the non-site related impact to the river is due to past alterations and current stresses imposed on it by development pressures.

One of the major concerns which prompted an ecological assessment at the Site was the potential migration of constituents from the Site downstream and the effects they might have on the fishery resource. This concern may be alleviated based on the following considerations:

- the Aberjona River supports a viable fish population within the limits of the Study Area;

- consistent with findings of the RI/FS (Roux Associates, 1983; 1984), most metals show little propensity to mobilize from soil or sediment into surface water. Those that do (e.g. zinc) show little potential for inducing toxicity due to the natural hardness of these waters;

- potential impacts due to suspended sediment are greatly diminished by the presence of wetlands, constructed for flood-control, which function to decrease flow and settle out particulate matter; and

- biologically persistent constituents (pesticides, organo-metals) were not detected.

Given these observations, and the fact that metals in sediment decrease markedly as a function of distance from the Site (Figures 11, 12, and 13), the opportunity for impact to the fishery resource of Upper Mystic Lake is negligible.

It does appear that a portion of the stream may be affected in the vicinity of the East-Central Hide Pile, probably due to the presence of leachate. However, the contribution of this leachate to the volume of the Aberjona is small (zero to one-sixteenth of the volume measured at SW-14), and does not appear to have an effect on the resident fish population below the Study Area.

Lower South Pond

This pond is currently targeted as an area for remediation, and discussion of impacts can be limited. Because of direct contact of surface water with metal containing soils and Hide Pile residues, it may serve as a potential source of constituents of concern to the Aberjona River.

This wetland provides suitable habitat for various wildlife, and the presence of these potential sources do not appear to deter fish or reptiles. Its function and value as a water resource would be enhanced by a combination of the planned remedial action and wetland mitigation measures.

Hall's Brook Holding Area

This area, ponded to the north and deep marsh wetland to the south, was altered to serve as a flood retention basin. Due to the manner in which it is constructed, the ponded area will never be a productive wetland. It is bordered by industries, railroad tracks, and a utility easement, and the profile of the basin accentuates anoxic conditions. In short, it was designed as a flood retention reservoir and is functioning as such.

The deep marsh to the south, also intended as a flood retention area, is more productive due to the presence of vegetation. It provides cover for nesting birds and slow, shallow waters for small fish and invertebrates.

Both wetlands serve to contribute much toward the renovation of surface water draining from the New Boston and Atlantic Avenue Drainways. The deeper waters of the Hall's Brook Holding Area allow siltation of fine suspended sediment, while the shallow waters of the deep marsh to the south replenish the surface waters with oxygen.

In summary, it can be said that, although the Site has obvious sources of constituents that may potentially degrade the water resource, current conditions (e.g. water chemistry, hydrology) appear to minimize the magnitude of the impact. Furthermore, the nature and location of these waters limit their value to wildlife.

4.4.13 Limitations of Analysis

The most difficult task in the evaluation of ecological data is trying to delineate which effects are due to the Site and which can be attributed to habitat or non-site related impacts. As mentioned previously, the Aberjona and its tributaries have been altered for the purposes of controlling the watershed within the industrial park. The destruction of available habitat, as well as the impacts of non-point sources associated with the large amount of development (e.g. road salt in stormwater runoff) contribute the largest degree of uncertainty to this EA.

Evaluation Using RBP

Evaluation of biological conditions and impacts using methods developed by the USEPA (RBP II) are effective in identifying stations of concern. However, the RBP used for this assessment is not wholly appropriate for the following reasons. First, two of the eight metrics rely on the presence of pollution-sensitive orders (Ephemeroptera, Plecoptera, and Trichoptera). Individuals representing these families were rarely abundant and, if so, were composed of taxa that are known to be tolerant of adverse environmental conditions (i.e., hydropsychid caddisflys). Secondly, the numbers and distribution of insects in this study precluded the use of the Functional Feeding Group metrics. Thirdly, the calculation of Family Biotic Index is most useful for the evaluation of impacts from organic wastes, and is not considered appropriate for the evaluation of impacts from inorganics. In short, although the results of the RBP II did illuminate impacted stations, it may be somewhat insensitive, due to the nature and distribution of the types of organisms collected, in the characterization of other stations as "moderately impaired".

Use of ER-L and ER-M Values

Comparison of the sediment concentrations of particular constituents at the Site with ER-L and ER-M values has a large degree of uncertainty associated with it due to the following reasons:

- impacts from constituents of concern in sediment are primarily a function of bioavailability, i.e., how much of the chemical will an organism be able to absorb to induce a toxic effect. This parameter is Site-specific and cannot be predicted;

- ER-L and ER-M values are almost exclusively based on marine studies, which limit their applicability for the evaluation of impacts within the fresh water habitat of the Aberjona watershed;

- values cited in Long and Morgan (1990) are based on effects seen in benthic substrates which contain a mixture of compounds. Thus, effects for individual constituents may be biased due to the presence of compounds other than that of the constituent in question; and

- measurement end points between each study are not consistent.

Use of AWQC to Evaluate Effects of a Mixture

Toxicity quotients were calculated for each metal (based on AWQC) and summed (within each station) to determine the potential impact of the mixture. This addition of "toxic units" was performed to evaluate each station's contribution of "risk" relative to other stations at the Site. Since each metal has a different mechanism of toxicity, the method helps to eliminate bias in evaluation of potential effects of the mixture. However, it is important to note that AWQC are usually derived by conservative methods, i.e., selecting the lowest concentration which had an adverse effect on the most sensitive species. Also, water-quality parameters (e.g. pH, D.O.) have a large influence on toxicity. These parameters affect bioavailability and, like sediment parameters, are highly site-specific. Finally, the summation is, by itself, meaningless. A summation greater than 1.0 does not indicate an exceedance of available AWQC, nor does it indicate that the occurrence of an adverse effect is possible.

5.0 SUMMARY AND CONCLUSIONS

The following sections summarize findings and conclusions of the GSIP RI. These conclusions incorporate an evaluation of hydrogeologic, stream-sediment and soils data developed during the PDI. In addition, this section provides a discussion of the limitations of the data developed during the GSIP RI and recommended remedial action objectives.

The nature and extent of inorganic and organic constituents, the fate and transport of these constituents and results of the risk assessment are summarized in this section. The summary in this section is based upon the results of the GSIP RI field investigations and results of the metals mobility and risk assessment tasks.

5.1 Nature and Extent of Inorganic and Organic Compounds

The nature and extent of inorganic and organic compounds were determined through collection and analysis of ground-water, surface-water, and stream-sediment samples during the GSIP RI program. In addition, ground-water and stream-sediment data, developed during the PDI, were evaluated to provide a comprehensive understanding of the nature and extent of inorganic and organic compounds in these media.

5.1.1 Ground Water

The following areas of impacted ground water were identified based upon results of the ground-water sampling conducted during the GSIP RI:

- benzene at the east flank of the West Hide Pile and in the area just south of Atlantic Avenue;
- toluene upgradient of well OW-16, north of the trailer compound, and in the area just south of Atlantic Avenue;
- dissolved arsenic downgradient from the West Hide Pile, East-Central Hide Pile, and South Hide Pile, with discharges of dissolved arsenic from the South Hide Pile into Hall's Brook Holding Area (Figure 8); and
- dissolved chromium downgradient from the West Hide Pile and the East-Central Hide Pile (Figure 9).

Ground-water flow patterns and the orientation of the plumes are controlled by the geologic conditions (i.e., the data developed during the GSIP and PDI programs) which indicate that the west and east branches of the minor, on-site buried valleys merge into a single, more deeply incised main buried valley near Observation Wells OW-18A/OW-18B and OW-17, and the Hall's Brook Holding Area.

5.1.2 Sewers

Sampling of the Town of Reading and City of Woburn trunk sewers demonstrated that concentrations of organic and inorganic compounds are not higher in the downstream samples than in the upstream samples.

5.1.3 Surface Water

A comparison of the types of organic and inorganic constituents detected near the upstream Site boundary, on-site, and downstream of the Site indicates that the compounds present in the upstream samples differ from those detected on-site, and downstream. The maximum concentrations of the eight organic compounds detected in surface-water samples collected upstream of the Site are listed below:

Bis(2-ethylhexyl)phthalate	5.0 μg/L
Chlorobenzene	2.0 μg/L
1,2-dichloroethane	6.0 μg/L
di-n-butylphthalate	4.0 μg/L
Methylene chloride	7.0 μg/L
Phenol	1.0 μg/L
Toluene	2.0 μg/L
Trichloroethene	6.0 μg/L

Chromium and lead were detected in the upstream samples at maximum concentrations of 62.6 and 8.6 μg/L, respectively.

Three organic compounds were detected in surface water on-site. Methylene chloride, bis(2-ethylhexyl)phthalate and di-n-butylphthalate were detected on-site at concentrations of 7.0, 6.0 and 4.0 μg/L, respectively. These concentrations are similar to constituent concentration

in the upstream Site boundary area. Benzene and toluene were not detected in surface water on-site. Maximum concentrations of arsenic, chromium, and lead detected in Site surface waters were 40.6, 30.3, and 6.3 μg/L, respectively. Organic compounds detected in downstream, off-site surface waters include chlorinated VOCs, methylene chloride, phthalates, and n-nitrosodiphenylamine.

5.1.4 Stream Sediments

Chlorinated VOCs, phthalates and PAHs were detected in upstream, on-site, and downstream sediment samples. Toluene was detected in upstream sediment samples, but not in on-site or off-site samples. Benzene was detected in downstream and upstream samples, but was not detected on-site. A similar suite of metals was detected upstream of the Site as was detected on-site, and downstream of the Site.

A two order of magnitude decrease in organic and inorganic constituent concentrations from SW-9 (the north end of Hall's Brook Holding Area) to SW-14 (the Aberjona River just north of Mishawum Road) indicates that the Hall's Brook Holding Area is trapping organic and inorganic constituents transported (on fine-grained sediment) from upstream, and preventing downstream migration of this sediment.

5.2 Fate and Transport

The fate and transport of organic and inorganic compounds within the Study Area are depicted on Overlays 1 through 4 (Please note that the overlays should be turned from right to left). Overlay 1 shows the geometry of the unconsolidated aquifer which controls ground-water flow patterns and, as a result, the transport of inorganic and organic compounds. Ground-water elevation contours and flow directions for May 13, 1991 are plotted on Overlay 2. Although the location of the water-level elevation contours changed throughout the year, the ground-water flow patterns have essentially remained the same. Overlay 3 displays the areal extent of arsenic, benzene and toluene in ground water while Overlay 4 outlines arsenic and benzene found in stream sediments within the Hall's Brook Holding Area. These overlays indicate the extent of migration from the Site through surface-water and ground-water pathways.

5.3 Metals Mobility

During the 1984 RI/FS, metals were detected in ground water but not to the extent that identifiable plumes could be mapped. During the PDI and GSIP RI investigations, two arsenic/chromium plumes were identified, one migrating away from the East-Central Hide Pile and another moving downgradient from the West Hide Pile. A conceptual geochemical model explaining the recent mobility of arsenic and chromium was derived from literature reports on the geochemical behavior of arsenic and chromium, and a thorough evaluation of site-specific geochemical data. In summary, the unique juxtaposition of anaerobically decaying hide residues, and metals-containing soils resulting from the placement of the hide piles in the late 1970s, created the conditions that allowed the formation of mobile metals.

Ground-water conditions below the hide piles are strongly reducing. Under reducing conditions, infiltration of precipitation through metal-containing soils and hide residues leaches arsenic and chromium. Through microbial activity, these metals form organic complexes which are even more mobile in ground water than their ionic forms. As these complexes move from reducing to oxidizing zones with ground-water flow, geochemical reactions occur which decrease the mobility of these metals, primarily by precipitation/sorption reactions. Chromium mobility decreases faster than arsenic mobility because it more readily complexes with iron hydroxides. However, arsenic precipitates and becomes immobilized as evidenced by the fact that, in areas of the Site where ground-water conditions are oxidizing, arsenic concentrations are less than 50 μg/L.

5.4 Risk Assessment

5.4.1 Human Health Evaluation

Substantial differences exist in the potential health impacts of the Site, depending upon the exposure scenario considered. Differences also exist in the certainty associated with the scenarios and the level of conservatism applied to each analysis.

Five exposure scenarios were analyzed which may apply to present or potential future use of the property. Of these analyses, only one, ingestion and household use of drinking water from a domestic source, produced estimated risks of greater than 1 in 100,000. The estimated risks for this improbable exposure scenario ranged between 10^{-5} to 10^{-4} for average constituent

concentrations and 10^{-2} to 10^{-3} for maximum constituent concentrations. Analysis of risks for a more reasonable exposure, such as consumption by an industrial worker, yielded a lower range of risk. As municipal water is available from other sources, both scenarios are considered a potential future use.

Estimated risk levels for uses of surface waters, such as fishing, swimming, and sediment contact, ranged from 10^{-5} for wading, swimming, and sediment ingestion to 10^{-6} for fish ingestion. The probability of such exposures occurring are, at present, very low.

The results of the risk characterization are summarized below.

SCENARIO	CANCER RISK		HAZARD (additive)	
	Average	Maximum	Average	Maximum
Ingestion of Ground Water	6.OE - 05	4.9E - 03	6.30	36.00
Ingestion of Fish	1.OE - 06	3.6E - 06	0.02	0.06
Wading in Lower South Pond	1.3E - 05	NA	0.01	NA
Swimming in HBHA (child)	6.2E - 05	NA	0.06	NA
Ingestion of Sediment (SW-16)	4.OE - 05	NA	0.22	NA
NA Maximum concentrations are not encountered during contact with surface water. Only one sample taken at SW-16; no maximum value available. HBHA = Hall's Brook Holding Area				

5.4.2 Ecological Evaluation

All stations evaluated showed signs of environmental stress, a combined result of both destruction of habitat and non-point impacts associated with development of the area. Based on the results of the physical, chemical, and biological data, acute Site-related effects were confined to the New Boston Street Drainway and West Branch (East and East-Central Hide Pile) of the Aberjona River. Depauperate communities within Hall's Brook Holding Area cannot be attributed solely to chemical impacts of the Site, as benthic conditions were anoxic. Internal and external examination of individual fish showed no gross abnormalities.

5.5 Data Limitations and Recommendations for Future Work

A GSIP RI Phase 2 Work Plan addressing Phase 1 data gaps will be submitted to the USEPA and MDEP within 30 days of submittal of this document.

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Table 3-1. Well Construction Data at the Industri-Plex Site, Woburn, Massachusetts.

Well Number	Field Program (1)	Well Diameter/ Well Material	Total Depth of Well (ft below land surface)	Elevation of Measuring Point (ft above mean sea level)	Elevation of Bottom (ft relative to mean sea level)	Stickup (ft above land surface)	Elevation of Screened Interval (2) (ft relative to mean sea level)	Type of Formation	Total Length of Screen (ft)
OW-1	RI/FS	6" steel	108.03	80.32	-28.60	0.89	55.40 - -28.60	bedrock	84.00
OW-1A	RI/FS	4" PVC	24.32	79.72	54.89	0.51	74.89 - 54.89	total unconsolidated	20.00
OW-4	RI/FS	6" steel	42.76	71.54	27.82	0.96	47.82 - 27.82	bedrock	20.00
OW-6	RI/FS	4" PVC	16.85	62.67	45.82	0.00	55.82 - 45.82	top unconsolidated	10.00
OW-7	RI/FS	4" PVC	31.49	57.88	25.74	0.65	55.74 - 25.74	total unconsolidated	30.00
OW-9	RI/FS	6" steel	127.31	68.88	-60.06	1.63	34.94 - -60.06	bedrock	95.00
OW-10	RI/FS	4" PVC	31.42	64.63	32.41	0.80	62.41 - 32.41	total unconsolidated	30.00
OW-11	RI/FS	4" PVC	41.11	71.22	28.90	1.21	68.90 - 28.90	total unconsolidated	40.00
OW-12	RI/FS	4" PVC	50.67	63.74	11.99	1.08	51.99 - 11.99	total unconsolidated	40.00
OW-13	RI/FS	4" PVC	32.15	64.99	32.84	0.00	57.84 - 32.84	total unconsolidated	25.00
OW-14	RI/FS	4" PVC	47.39	65.54	17.04	1.11	62.04 - 17.04	total unconsolidated	45.00
OW-15	RI/FS	6" steel	25.82	64.60	38.29	0.49	58.29 - 38.29	total unconsolidated	20.00
OW-16	RI/FS	4" PVC	35.83	67.29	30.31	1.15	50.31 - 30.31	basal unconsolidated	20.00
OW-17	RI/FS	4" PVC	25.27	57.86	31.54	1.05	51.54 - 31.54	total unconsolidated	20.00
OW-18	RI/FS	6" PVC	55.15	62.76	7.30	0.31	47.30 - 7.30	basal unconsolidated	40.00
OW-18A	RI/FS	4" PVC	15.20	62.08	46.11	0.77	56.11 - 46.11	top unconsolidated	10.00

NOTES:
(1)   GSIP = Well installed as part of GSIP program.
      PDI = Well installed as part of PDI program.
      RI/FS = Well installed as part of RI/FS program.
(2) Bedrock wells are finished as unscreened boreholes.

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OW-19	RI/FS	6" PVC	67.00	55.97	-12.57	1.54	17.43	- -12.57	basal unconsolidated	30.00
OW-19A	RI/FS	4" PVC	38.60	55.87	16.19	1.08	51.19	- 16.19	top unconsolidated	35.00
OW-20	RI/FS	4" PVC	90.72	57.33	-33.39	0.00	16.61	- -33.39	basal unconsolidated	50.00
OW-21	GSIP	4" PVC	15.04	76.28	58.71	2.53	68.71	- 58.71	top unconsolidated	10.00
OW-22	GSIP	2" PVC	13.52	81.76	65.12	3.12	75.12	- 65.12	total unconsolidated	10.00
OW-23	PDI	4" PVC	27.00	68.54	38.54	3.00	48.69	- 38.54	middle unconsolidated	10.15
OW-24A	PDI	4" PVC	24.97	57.47	33.10	-0.60	43.25	- 33.10	middle unconsolidated	10.15
OW-24B	PDI	4" PVC	59.65	57.26	-2.89	-0.50	7.26	- -2.89	basal unconsolidated	10.15
OW-25A	PDI	4" PVC	23.00	66.00	43.30	-0.30	53.45	- 43.30	top unconsolidated	10.15
OW-25B	PDI	4" PVC	39.42	65.34	26.70	-0.78	36.90	- 26.70	basal unconsolidated	10.20
OW-26A	PDI	4" PVC	23.20	64.15	39.05	1.90	49.20	- 39.05	middle unconsolidated	10.15
OW-26B	PDI	4" PVC	41.46	63.80	20.04	2.30	30.20	- 20.04	basal unconsolidated	10.15
OW-27A	PDI	4" PVC	40.32	70.84	28.11	2.41	38.26	- 28.11	middle unconsolidated	10.15
OW-27B	PDI	4" PVC	94.57	70.52	-25.48	1.43	-10.33	- -25.48	basal unconsolidated	10.15
OW-28	GSIP	4" PVC	8.92	77.19	65.64	2.63	70.64	- 65.64	top unconsolidated	5.00
OW-29	PDI	4" PVC	25.70	61.17	36.10	-0.63	46.25	- 36.10	middle unconsolidated	10.15

NOTES:
(1)   GSIP = Well installed as part of GSIP program.
      PDI = Well installed as part of PDI program.
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(2) Bedrock wells are finished as unscreened boreholes.

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OW-30A	PDI	4" PVC	18.72	65.90	45.18	2.00	55.33 - 45.18	top unconsolidated	10.15
OW-30B	PDI	4" PVC	57.83	65.60	5.27	2.50	15.42 - 5.27	basal unconsolidated	10.15
OW-31	PDI	4" PVC	14.00	74.35	57.90	3.05	59.90 - 57.90	middle unconsolidated	5.00
OW-32	PDI	4" PVC	8.00	75.47	64.00	3.77	66.20 - 64.00	middle unconsolidated	2.20
OW-33A	PDI	4" PVC	44.40	56.83	10.03	2.40	20.23 - 10.03	middle unconsolidated	10.20
OW-33B	PDI	4" PVC	84.01	56.66	-29.65	2.30	-19.50 - -29.65	basal unconsolidated	10.15
OW-36	PDI	4" PVC	12.9	74.86	59.80	2.16	69.80 - 59.80	top unconsolidated	10.00
OW-37	PDI	4" PVC	15.72	72.60	53.58	3.30	63.78 - 53.58	top unconsolidated	10.20
OW-38	PDI	4" PVC	15.5	71.40	54.30	1.60	64.50 - 54.30	top unconsolidated	10.20
OW-39	PDI	4" PVC	15.1	74.14	56.70	2.34	66.70 - 56.70	top unconsolidated	10.00
OW-40	PDI	4" PVC	17.0	71.64	51.70	2.94	61.90 - 51.70	top unconsolidated	10.20
OW-41	PDI	4" PVC	16.0	66.95	51.50	-0.55	61.70 - 51.50	top unconsolidated	10.20
OW-42	PDI	4" PVC	34.0	69.80	33.00	2.80	43.20 - 33.00	basal unconsolidated	10.20
OW-43	PDI	4" PVC	14.0	76.17	60.60	1.57	70.60 - 60.60	top unconsolidated	10.00
OW-44	PDI	4" PVC	16.5	70.60	53.30	1.30	62.80 - 53.30	top unconsolidated	9.50
OW-45	PDI	4" PVC	17.0	70.84	52.40	1.44	62.40 - 52.40	top unconsolidated	10.00

NOTES:
(1) GSIP = Well installed as part of GSIP program.
    PDI = Well installed as part of PDI program.
    RI/FS = Well installed as part of RI/FS program.
(2) Bedrock wells are finished as unscreened boreholes.

ROUX ASSOCIATES INC

MO06609Dy.1D.3

Table 3-1. Well Construction Data at the Industri-Plex Site, Woburn, Massachusetts.

Well Number	Field Program (1)	Well Diameter/ Well Material	Total Depth of Well (ft below land surface)	Elevation of Measuring Point (ft above mean sea level)	Elevation of Bottom (ft relative to mean sea level)	Stickup (ft above land surface)	Elevation of Screened Interval (2) (ft relative to mean sea level)	Type of Formation	Total Length of Screen (ft)
OW-46	PDI	4" PVC	13.5	67.88	55.20	-0.32	64.70 - 55.20	top unconsolidated	9.50
OW-47	PDI	4" PVC	16.5	69.23	51.80	1.43	61.30 - 51.80	top unconsolidated	9.50
OW-48	PDI	4" PVC	65.75	64.72	-2.00	1.72	7.25 - -2.00	basal unconsolidated	9.25
OW-48A	PDI	4" PVC	24.5	64.39	38.70	1.69	48.20 - 38.70	middle unconsolidated	9.50
OW-49	PDI	4" PVC	56.0	66.06	8.20	1.86	18.20 - 8.20	basal unconsolidated	10.00
OW-49A	PDI	4" PVC	26.0	66.42	39.20	1.22	49.20 - 39.20	middle unconsolidated	10.00
OW-50	PDI	4" PVC	76.0	68.38	-9.20	1.58	0.80 - -9.20	basal unconsolidated	10.00
OW-50A	PDI	4" PVC	28.5	68.00	38.50	1.50	48.00 - 38.50	middle unconsolidated	9.50

NOTES:
(1)   GSIP = Well installed as part of GSIP program.
     PDI = Well installed as part of PDI program.
     RI/FS = Well installed as part of RI/FS program.
(2) Bedrock wells are finished as unscreened boreholes.

MO06609Dy.1D.3

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Table 3-2.   Soil Sample Field Measurements at the Industri-Plex Site,
             Woburn, Massachusetts.

Sample Designation/Depth (feet below land surface)	Date/Time of Measurement	Saturated or Unsaturated	Eh (mV)
SS-22/4-6	3-1-90/1840 hrs.	U	+188.7
SS-22/6-7.2	3-1-90/1840 hrs.	S	+222.3
SS-28/0-7	3-8-90/1025 hrs.	U	+220.8
SS-28/7-9	3-8-90/1025 hrs.	S	+65.2
SS-21/0-2	3-13-90/0845 hrs.	U	+316.0
SS-21/2-8	3-13-90/0845 hrs.	S	+160.7

Table 3-3.   Hydrogeologic Units and Aquifer Characteristics, Industri-Plex Site, Woburn Massachusetts

HYDROGEOLOGIC UNIT	DESCRIPTION	AQUIFER CHARACTERISTICS			
		T	S	K_r	K_z
Qo4	Glacial Outwash Lake/Pond and Alluvial Fan Deposits	16,620 - 16,848	0.001 - 0.25	276 - 280	6 - 8
Qo3	Glacial Outwash Braided Stream Deposits	83,725 - 140,400	0.01 - 0.07	1,392 - 2,335	45-72
Qo2	Glacial Stream/Lake Deposits	92,600 - 111,267	0.001 - 0.002	1,057 - 1,436	6 - 26
Qsd	Peat and Swamp Deposits	NA	NA	NA	NA

Notes: Only units within the unconsolidated aquifer are included.

T = Transmissivity
S = Storage Coefficient
K_r = Horizontal Hydraulic Conductivity
K_z = Vertical Hydraulic Conductivity
NA = Not Available

Table 3-4. Comparison of Hydraulic Conductivity Values from Slug Tests Performed by Golder Associates Inc. November 5, 1990 through November 9, 1990, and Hydraulic Conductivity Values from Constant-Rate (Pumping) Test Performed by Roux Associates, Inc., October 31, 1990 through November 2, 1990, Industri-Plex Site, Woburn, Massachusetts.

| Well Number | Slug Tests | | | | Stallman Method | Pumping Tests | |
| | Bouwer and Rice Analysis | | Hvorslev Analysis | | | Neumann Method | Hantash Method |
	Hydraulic Conductivity in gpd/square ft Falling Head Test	Hydraulic Conductivity in gpd/square ft Rising Head Test	Hydraulic Conductivity in gpd/square ft Falling Head Test	Hydraulic Conductivity in gpd/square ft Rising Head Test	Hydraulic Conductivity in gpd/square ft	Hydraulic Conductivity in gpd/square ft	Hydraulic Conductivity in gpd/square ft
OW-19	8.18E+01	1.08E+02	8.52E+01	8.12E+01	NAp	1.58E+03	1.08E+03
OW-19A	4.75E+02	3.20E+02	9.86E+02	6.02E+02	NAp	5.39E+02	NAp
TW-1S	NA	NA	2.54E+02	5.13E+02	6.00E+02	4.10E+02	1.97E+03
TW-1D	3.22E+01	3.63E+01	6.79E+01	5.85E+01	2.27E+03	1.85E+03	NAp
TW-2S	NA	NA	1.01E+03	1.38E+02	6.18E+02	4.97E+02	2.03E+03
TW-2D	1.59E+01	1.41E+01	1.54E+01	2.27E+01	2.34E+03	1.99E+03	NAp
TW-3S	3.27E+02	2.10E+02	4.81E+02	3.54E+02	2.80E+02	2.76E+02	1.81E+03
TW-3D	1.52E+02	1.63E+02	2.31E+02	2.16E+02	1.83E+03	2.06E+03	NAp
TW-4S	8.88E+02	NA	9.33E+02	NA	1.08E+03	8.95E+02	1.67E+04
TW-4D	7.59E+02	1.25E+03	1.09E+03	1.52E+03	3.00E+03	2.61E+03	

NA = Test data was invalid due to either no displacement or fast recovery (within 3 seconds)
NAp = Not applicable because no unique fit between data and type curves
gpd/square ft = gallons per day per square foot

Table 3-4. Comparison of Hydraulic Conductivity Values from Slug Tests Performed by Golder Associates Inc. November 5, 1990 through November 9, 1990, and Hydraulic Conductivity Values from Constant-Rate (Pumping) Test Performed by Roux Associates, Inc., October 31, 1990 through November 2, 1990, Industri-Plex Site, Woburn, Massachusetts.

| | Slug Tests | | | | Pumping Tests | | |
| | Bouwer and Rice Analysis | | Hvorslev Analysis | | Stallman Method | Neumann Method | Hantush Method |
Well Number	Hydraulic Conductivity in gpd/square ft Falling Head Test	Hydraulic Conductivity in gpd/square ft Rising Head Test	Hydraulic Conductivity in gpd/square ft Falling Head Test	Hydraulic Conductivity in gpd/square ft Rising Head Test	Hydraulic Conductivity in gpd/square ft	Hydraulic Conductivity in gpd/square ft	Hydraulic Conductivity in gpd/square ft
OW-19	8.18E+01	1.08E+02	8.52E+01	8.12E+01	NAp	1.58E+03	1.08E+03
OW-19A	4.75E+02	3.20E+02	9.86E+02	6.02E+02	NAp	5.39E+02	NAp
TW-1S	NA	NA	2.54E+02	5.13E+02	6.00E+02	4.10E+02	NAp
TW-1D	3.22E+01	3.63E+01	6.79E+01	5.85E+01	2.27E+03	1.85E+03	1.97E+03
TW-2S	NA	NA	1.01E+03	1.38E+02	6.18E+02	4.97E+02	NAp
TW-2D	1.59E+01	1.41E+01	1.54E+01	2.27E+01	2.34E+03	1.99E+03	2.03E+03
TW-3S	3.27E+02	2.10E+02	4.81E+02	3.54E+02	2.80E+02	2.76E+02	NAp
TW-3D	1.52E+02	1.63E+02	2.31E+02	2.16E+02	1.83E+03	2.06E+03	1.81E+03
TW-4S	8.88E+02	NA	9.33E+02	NA	1.08E+03	8.95E+02	NAp
TW-4D	7.59E+02	1.25E+03	1.09E+03	1.52E+03	3.00E+03	2.61E+03	1.67E+03

NA = Test data was invalid due to either no displacement or fast recovery (within 3 seconds)
NAp = Not applicable because no unique fit between data and type curves
gpd/square ft = gallons per day per square foot

Table 3-5. Ground-Water Elevation Data at the Industri-Plex Site, Woburn, Massachusetts.

Well Number	Elevation of Measuring Point (ft above mean sea level)	April 10, 1990		May 24, 1990		May 30, 1990	
		Depth to Water from Measuring Point (ft below measuring point)	Elevation of Ground Water (ft above mean sea level)	Depth to Water from Measuring Point (ft below measuring point)	Elevation of Ground Water (ft above mean sea level)	Depth to Water from Measuring Point (ft below measuring point)	Elevation of Ground Water (ft above mean sea level)
OW-1*	80.32	7.15	73.17	6.95	73.37	6.27	74.05
OW-1A	79.72	5.45	74.27	5.20	74.52	4.35	75.37
OW-4*	71.54	4.88	66.66	4.90	66.64	5.14	66.40
OW-6	62.67	8.00	54.67	8.09	54.58	7.86	54.81
OW-7	57.88	--	--	6.28	51.60	6.16	51.72
OW-9*	68.88	9.25	59.63	9.09	59.79	9.20	59.68
OW-10	64.63	4.18	60.45	4.16	60.47	3.91	60.72
OW-11	71.22	4.01	67.21	4.04	67.18	3.55	67.67
OW-12	63.74	6.60	57.14	6.60	57.14	6.49	57.25
OW-13	64.99	3.76	61.23	3.85	61.14	3.50	61.49
OW-14	65.54	6.49	59.05	6.53	59.01	6.49	59.05
OW-15	64.60	3.90	60.70	4.80	59.80	3.23	61.37
OW-16	67.29	3.34	63.95	3.54	63.75	3.18	64.11
OW-17	57.86	5.64	52.22	5.70	52.16	4.93	52.93
OW-18	62.76	8.45	54.31	8.47	54.29	7.93	54.83
OW-18A	62.08	7.77	54.31	7.84	54.24	7.29	54.79
OW-19	55.97	3.88	52.09	3.99	51.98	3.20	52.77
OW-19A	55.87	3.80	52.07	3.91	51.96	3.09	52.78
OW-20	57.33	5.93	51.40	5.97	51.36	5.54	51.79
OW-21	76.28	4.86	71.42	4.88	71.40	4.57	71.71
OW-22	81.76	7.98	73.78	7.89	73.87	7.65	74.11
OW-23	68.54	**	**	**	**	**	**
OW-24A	57.47	**	**	**	**	**	**
OW-24B	57.26	**	**	**	**	**	**
OW-25A	66.00	**	**	14.18	51.82	--	--
OW-25B	65.34	**	**	13.66	51.68	--	--
OW-26A	64.15	**	**	**	**	**	**
OW-26B	63.80	**	**	**	**	**	**
OW-27A	70.84	**	**	**	**	**	**
OW-27B	70.52	**	**	**	**	**	**
OW-28	77.195	7.23	69.97	9.35	67.85	9.75	67.45
OW-29	61.17	**	**	5.18	55.99	--	--
OW-30A	65.90	**	**	**	**	**	**
OW-30B	65.60	**	**	**	**	**	**
OW-33A	56.83	**	**	**	**	**	**
OW-33B	56.66	**	**	4.74	51.92	**	**

NOTES:
* Bedrock well.
** Well not yet installed.
-- No measurement taken.

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Table 3-5. Ground-Water Elevation Data at the Industri-Plex Site, Woburn, Massachusetts.

Well Number	Elevation of Measuring Point (ft above mean sea level)	June 20, 1990		June 26, 1990		July 17, 1990	
		Depth to Water from Measuring Point (ft below measuring point)	Elevation of Ground Water (ft above mean sea level)	Depth to Water from Measuring Point (ft below measuring point)	Elevation of Ground Water (ft above mean sea level)	Depth to Water from Measuring Point (ft below measuring point)	Elevation of Ground Water (ft above mean sea level)
OW-1*	80.32	7.62	72.70	7.86	72.46	8.24	72.08
OW-1A	79.72	6.50	73.22	6.79	72.93	7.36	72.36
OW-4*	71.54	6.91	64.63	7.40	64.14	8.75	62.79
OW-6	62.67	8.70	53.97	8.92	53.75	9.05	53.62
OW-7	57.88	6.93	50.95	7.09	50.79	7.35	50.53
OW-9*	68.88	10.00	58.88	10.33	58.55	11.03	57.85
OW-10	64.63	5.22	59.41	5.58	59.05	6.38	58.25
OW-11	71.22	4.50	66.72	4.71	66.51	4.99	66.23
OW-12	63.74	7.49	56.25	7.75	55.99	8.31	55.43
OW-13	64.99	4.74	60.25	5.00	59.99	5.42	59.57
OW-14	65.54	7.54	58.00	7.87	57.67	8.56	56.98
OW-15	64.60	4.43	60.17	4.64	59.96	5.06	59.54
OW-16	67.29	4.21	63.08	4.40	62.89	5.01	62.28
OW-17	57.86	6.04	51.82	6.21	51.65	6.35	51.51
OW-18	62.76	9.06	53.70	9.30	53.46	9.55	53.21
OW-18A	62.08	8.40	53.68	8.66	53.42	8.89	53.19
OW-19	55.97	4.53	51.44	4.68	51.29	5.02	50.95
OW-19A	55.87	4.45	51.42	4.74	51.13	4.95	50.92
OW-20	57.33	6.57	50.76	6.72	50.61	6.97	50.36
OW-21	76.28	5.44	70.84	5.79	70.49	6.19	70.09
OW-22	81.76	9.16	72.60	9.52	72.24	10.82	70.94
OW-23	68.54	14.62	53.92	15.66	52.88	15.34	53.20
OW-24A	57.47	5.15	52.32	5.35	52.12	5.70	51.77
OW-24B	57.26	5.04	52.22	5.24	52.02	5.59	51.67
OW-25A	66.00	14.87	51.13	15.10	50.90	15.31	50.69
OW-25B	65.34	14.19	51.15	14.44	50.90	14.65	50.69
OW-26A	64.15	9.37	54.78	9.68	54.47	10.22	53.93
OW-26B	63.80	9.09	54.71	9.39	54.41	9.81	53.99
OW-27A	70.84	18.34	52.50	18.53	52.31	18.88	51.96
OW-27B	70.52	19.15	51.37	19.32	51.20	19.56	50.96
OW-28	77.195	11.51	65.685	11.51	65.685	dry	dry
OW-29	61.17	5.05	55.67	5.62	55.55	5.93	55.24
OW-30A	65.90	11.80	54.10	12.52	53.38	12.85	53.05
OW-30B	65.60	12.14	53.46	12.36	53.24	12.65	52.95
OW-33A	56.83	5.83	51.00	6.02	50.81	6.27	50.56
OW-33B	56.66	5.63	51.03	5.77	50.89	6.10	50.56

NOTES:
* Bedrock well.

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Table 3-5. Ground-Water Elevation Data at the Industri-Plex Site, Woburn, Massachusetts.

Well Number	Elevation of Measuring Point (ft above mean sea level)	August 13, 1990		September 26, 1990	
		Depth to Water from Measuring Point (ft below measuring point)	Elevation of Ground Water (ft above mean sea level)	Depth to Water from Measuring Point (ft below measuring point)	Elevation of Ground Water (ft above mean sea level)
OW-1*	80.32	7.19	73.13	8.28	72.04
OW-1A	79.72	6.01	73.71	7.50	72.22
OW-4*	71.54	4.99	66.55	8.11	63.43
OW-6	62.67	7.52	55.15	8.80	53.87
OW-7	57.88	5.97	51.91	7.13	50.75
OW-9*	68.88	10.06	58.82	10.91	57.97
OW-10	64.63	4.26	60.37	6.03	58.60
OW-11	71.22	3.88	67.34	4.84	66.38
OW-12	63.74	6.68	57.06	8.20	55.54
OW-13	64.99	3.54	61.45	5.11	59.88
OW-14	65.54	6.69	58.85	8.37	57.17
OW-15	64.60	3.88	60.72	4.74	59.86
OW-16	67.29	3.32	63.97	3.42	63.87
OW-17	57.86	5.58	52.28	6.25	51.61
OW-18	62.76	8.36	54.40	9.45	53.31
OW-18A	62.08	7.74	54.34	8.82	53.26
OW-19	55.97	3.46	52.51	4.75	51.22
OW-19A	55.87	3.37	52.50	4.67	51.20
OW-20	57.33	5.70	51.63	6.78	50.55
OW-21	76.28	5.01	71.27	5.90	70.38
OW-22	81.76	9.23	72.53	11.34	70.42
OW-23	68.54	--	--	14.97	53.57
OW-24A	57.47	4.07	53.40	5.43	52.04
OW-24B	57.26	3.86	53.40	5.30	51.96
OW-25A	66.00	13.42	52.58	15.10	50.90
OW-25B	65.34	12.88	52.46	14.43	50.91
OW-26A	64.15	8.33	55.82	9.76	54.39
OW-26B	63.80	7.91	55.89	9.31	54.49
OW-27A	70.84	16.64	54.20	18.67	52.17
OW-27B	70.52	18.46	52.06	19.42	51.10
OW-28	77.195	9.25	67.95	dry	--
OW-29	61.17	5.34	55.83	5.92	55.25
OW-30A	65.90	11.79	54.11	12.78	53.12
OW-30B	65.60	11.64	53.96	12.48	53.12
OW-33A	56.83	4.64	52.19	5.99	50.84
OW-33B	56.66	4.55	52.11	5.93	50.73

NOTES:
* Bedrock well.
-- Well not located.

ROUX ASSOCIATES INC

Table 3-5. Ground-Water Elevation Data at the Industri-Plex Site, Woburn, Massachusetts.

Well Number	Elevation of Measuring Point (ft above mean sea level)	December 7, 1990		February 26, 1991		April 17-19, 1991	
		Depth to Water from Measuring Point (ft below measuring point)	Elevation of Ground Water (ft above mean sea level)	Depth to Water from Measuring Point (ft below measuring point)	Elevation of Ground Water (ft above mean sea level)	Depth to Water from Measuring Point (ft below measuring point)	Elevation of Ground Water (ft above mean sea level)
OW-1*	80.32	7.43	72.89	7.45	72.87	7.79	72.53
OW-1A	79.72	6.29	73.43	6.27	73.45	6.73	72.99
OW-4*	71.54	5.83	65.71	5.83	65.71	6.76	64.78
OW-6	62.67	8.23	54.44	8.18	54.49	8.51	54.16
OW-7	57.88	6.44	51.44	6.55	51.33	6.86	51.02
OW-9*	68.88	9.97	58.91	9.27	59.61	28.36**	40.52**
OW-10	64.63	4.68	59.95	4.71	59.92	5.51	59.12
OW-11	71.22	4.20	67.02	4.23	66.99	4.55	66.67
OW-12	63.74	7.25	56.49	7.00	56.74	7.52	56.22
OW-13	64.99	4.50	60.49	4.20	60.79	4.74	60.25
OW-14	65.54	7.33	58.21	6.71	58.83	8.65	56.89
OW-15	64.60	4.07	60.53	4.10	60.50	4.24	60.36
OW-16	67.29	4.06	63.23	3.68	63.61	2.70	64.59
OW-17	57.86	5.76	52.10	5.95	51.91	6.09	51.77
OW-18	62.76	8.76	54.00	8.73	54.03	9.09	53.67
OW-18A	62.08	7.82	54.26	8.05	54.03	8.41	53.67
OW-19	55.97	4.05	51.92	4.19	51.78	4.44	51.53
OW-19A	55.87	3.96	51.91	4.10	51.77	4.33	51.54
OW-20	57.33	6.13	51.20	6.20	51.13	6.49	50.84
OW-21	76.28	4.93	71.35	3.25	73.03	5.44	70.84
OW-22	81.76	8.97	72.79	8.25	73.51	9.00	72.76
OW-23	68.54	14.19	54.35	14.13	54.41	14.61	53.93
OW-24A	57.47	5.69	51.78	4.77	52.70	5.09	52.38
OW-24B	57.26	4.56	52.70	4.67	52.59	5.02	52.24
OW-25A	66.00	14.27	51.73	14.44	51.56	14.48	51.52
OW-25B	65.34	13.64	51.70	13.79	51.55	14.03	51.31
OW-26A	64.15	8.84	55.31	8.75	55.40	9.22	54.93
OW-26B	63.80	8.54	55.26	8.48	55.32	8.89	54.91
OW-27A	70.84	18.11	52.73	18.19	52.65	18.57	52.27
OW-27B	70.52	18.98	51.54	18.91	51.61	19.17	51.35
OW-28	77.20	dry	--	10.43	66.77	dry	--
OW-29	61.17	5.52	55.65	5.34	55.83	5.60	55.57
OW-30A	65.90	12.20	53.70	12.18	53.72	12.49	53.41
OW-30B	65.60	12.05	53.55	11.99	53.61	12.27	53.33
OW-31	74.35	3.29	71.06	2.50	71.85	4.28	70.07
OW-32	75.47	3.86	71.61	3.06	72.41	4.80	70.67

NOTES:
 * Bedrock well.
 ** Depth to water measurement suspect when compared to historical data.

ROUX ASSOCIATES INC

Table 3-5. Ground-Water Elevation Data at the Industri-Plex Site, Woburn, Massachusetts.

Well Number	Elevation of Measuring Point (ft above mean sea level)	December 7, 1990		February 26, 1991		April 17-19, 1991	
		Depth to Water from Measuring Point (ft below measuring point)	Elevation of Ground Water (ft above mean sea level)	Depth to Water from Measuring Point (ft below measuring point)	Elevation of Ground Water (ft above mean sea level)	Depth to Water from Measuring Point (ft below measuring point)	Elevation of Ground Water (ft above mean sea level)
OW-33A	56.83	5.31	51.52	5.40	51.43	5.72	51.11
OW-33B	56.66	5.13	51.53	5.23	51.43	5.50	51.16
OW-36	74.86	4.51	70.35	3.44	71.42	5.52	69.34
OW-37	72.60	4.78	67.82	4.43	68.17	5.67	66.93
OW-38	71.40	6.96	64.44	6.15	65.25	7.56	63.84
OW-39	74.14	9.28	64.86	8.90	65.24	9.41	64.73
OW-40	71.64	12.04	59.60	11.41	60.24	12.09	59.55
OW-41	66.95	7.02	59.93	6.13	60.82	6.25	60.70
OW-42	69.80	16.92	52.88	16.82	52.98	17.10	52.70
OW-43	76.17					8.61	67.56
OW-44	70.60					2.94	67.66
OW-45	70.84					4.89	65.95
OW-46	67.88					3.68	64.20
OW-47	69.23					10.55	58.68
OW-48	64.72					8.09	56.63
OW-48A	64.39					7.74	56.65
OW-49	66.06					9.82	56.24
OW-49A	66.42					10.35	56.07
OW-50	68.38					13.18	55.20
OW-50A	68.00					12.75	55.25

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Table 3-5. Ground-Water Elevation Data at the Industri-Plex Site, Woburn, Massachusetts.

May 13, 1991

Well Number	Elevation of Measuring Point (ft above mean sea level)	Depth to Water from Measuring Point (ft below measuring point)	Elevation of Ground Water (ft above mean sea level)
OW-1*	80.32	7.60	72.72
OW-1A	79.72	6.32	73.40
OW-4*	71.54	6.05	65.49
OW-6	62.67	8.32	54.35
OW-7	57.88	6.72	51.16
OW-9*	68.88	9.58	59.30
OW-10	64.63	4.85	59.78
OW-11	71.22	4.32	66.90
OW-12	63.74	7.11	56.63
OW-13	64.99	4.28	60.71
OW-14	65.54	7.10	58.44
OW-15	64.60	4.17	60.43
OW-16	67.29	3.91	63.38
OW-17	57.86	6.02	51.84
OW-18	62.76	8.87	53.89
OW-18A	62.08	8.24	53.84
OW-19	55.97	4.32	51.65
OW-19A	55.87	4.24	51.63
OW-20	57.33	6.35	50.98
OW-21	76.28	5.16	71.12
OW-22	81.76	9.56	72.20
OW-23	68.54	14.22	54.32
OW-24A	57.47	4.93	52.54
OW-24B	57.26	4.97	52.29
OW-25A	66.00	14.61	51.39
OW-25B	65.34	13.95	51.39
OW-26A	64.15	8.82	55.33
OW-26B	63.80	8.54	55.26
OW-27A	70.84	18.37	52.47
OW-27B	70.52	18.92	51.60
OW-28	77.20	dry	--
OW-29	61.17	5.46	55.71
OW-30A	65.90	12.27	53.63
OW-30B	65.60	12.14	53.46
OW-31	74.35	3.88	70.47
OW-32	75.47	4.35	71.12

NOTES:
* Bedrock well.

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Table 3-5. Ground-Water Elevation Data at the Industri-Plex Site, Woburn, Massachusetts.

	May 13, 1991		
Well Number	Elevation of Measuring Point (ft above mean sea level)	Depth to Water from Measuring Point (ft below measuring point)	Elevation of Ground Water (ft above mean sea level)
OW-33A	56.83	5.60	51.23
OW-33B	56.66	5.38	51.28
OW-36	74.86	4.78	70.08
OW-37	72.60	5.04	67.56
OW-38	71.40	6.77	64.63
OW-39	74.14	8.83	65.31
OW-40	71.64	11.75	59.89
OW-41	66.95	5.88	61.07
OW-42	69.80	16.91	52.89
OW-43	76.17	7.34	68.83
OW-44	70.60	2.41	68.19
OW-45	70.84	4.28	66.56
OW-46	67.88	3.43	64.45
OW-47	69.23	9.79	59.44
OW-48	64.72	7.73	56.99
OW-48A	64.39	7.36	57.03
OW-49	66.06	9.50	56.56
OW-49A	66.42	9.62	56.80
OW-50	68.38	12.88	55.50
OW-50A	68.00	12.40	55.60

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Table 3-6.   Calculation of Vertical Gradients in Monitoring Well Clusters, Industri-Plex Site, Woburn, Massachusetts.

Well	Elevation M.P. (1)	Height of M.P. (Feet)	Elevation of Ground (1)	Depth to Top of Screen (2)	Elevation Top of Screen (1)	Depth to Bottom of Screen (2)
OW-18	62.76	0.31	62.45	15.15	47.30	55.15
OW-18A	62.08	0.77	61.31	5.20	56.11	15.20
OW-19	55.97	1.54	54.43	37.00	17.43	67.00
OW-19A	55.87	1.08	54.79	3.60	51.19	38.60
OW-24A	57.47	0	57.47	14.82	42.65	24.97
OW-24B	57.26	0	57.26	49.5	7.76	59.65
OW-25A	66	0	66	12.85	53.15	23
OW-25B	65.34	0	65.34	29.22	36.12	39.42
OW-26A	64.15	1.9	62.25	13.05	49.2	23.2
OW-26B	63.8	2.3	61.5	31.31	30.19	41.46
OW-27A	70.84	2.4	68.44	30.17	38.27	40.32
OW-27B	70.52	1.4	69.12	84.42	-15.3	94.57
OW-30A	65.9	2	63.90	8.57	55.33	18.72
OW-30B	65.6	2.5	63.10	47.68	15.42	57.83
OW-33A	56.83	2.3	54.53	34.20	20.33	44.4
OW-33B	56.66	2.2	54.46	73.86	-19.4	84.01

Notes:

(1) Feet Above Mean Sea Level
(2) Feet Below Land Surface
dh = Difference of Elevation
dl = Distance Between Midpoints of Screen

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Table 3-6.   Calculation of Vertical Gradients in Monitoring Well Clusters, Industri-Plex Site, Woburn, Massachusetts.

Well	Elevation Bottom of Screen (1)	Elevation Midpoint of Screen (1)	Water Level June 20, 1990	dh (ft) June 20, 1990	dl (ft) June 20, 1990	I_v June 20, 1990	Direction of Flow June 20, 1990
OW-18	7.30	27.30	53.70				
OW-18A	46.11	51.11	53.68	-0.02	23.81	.0008	Upward
OW-19	-12.57	2.43	51.44				
OW-19A	16.19	33.69	51.42	-0.02	31.26	0.0006	Upward
OW-24A	32.5	37.57	52.32				
OW-24B	-2.39	2.68	52.22	0.10	34.89	0.003	Downward
OW-25A	43	48.07	51.13				
OW-25B	25.92	31.02	51.15	-0.02	17.05	0.001	Upward
OW-26A	39.05	44.12	54.78				
OW-26B	20.04	25.11	54.71	0.07	19.01	0.004	Downward
OW-27A	28.12	33.19	52.50				
OW-27B	-25.45	-20.37	51.37	1.13	53.56	0.021	Downward
OW-30A	45.18	50.25	54.10				
OW-30B	5.27	10.34	53.46	0.64	39.91	0.016	Downward
OW-33A	10.13	15.23	51.00				
OW-33B	-29.55	-24.47	51.03	-0.03	39.70	0.001	Upward

Notes:

(1) Feet Above Mean Sea Level
(2) Feet Below Land Surface
dh = Difference of Elevation
dl = Distance Between Midpoints of Screen
I_v = Vertical hydraulic gradient

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MO06609Dy.1D.3

Table 3-6. Calculation of Vertical Gradients in Monitoring Well Clusters, Industri-Plex Site, Woburn, Massachusetts.

Well	Elevation Bottom of Screen (1)	Elevation Midpoint of Screen (1)	Water Level June 26, 1990	dh (ft) June 26, 1990	dl (ft) June 26, 1990	I_v June 26, 1990	Direction of Flow June 26, 1990
OW-18	7.30	27.30	53.46				
OW-18A	46.11	51.11	54.42	-0.04	23.81	0.002	Upward
OW-19	-12.57	2.43	51.29				
OW-19A	16.19	33.69	51.13	-0.16	31.26	0.005	Upward
OW-24A	32.5	37.57	52.12				
OW-24B	-2.39	2.68	52.02	0.10	34.89	0.003	Downward
OW-25A	43	48.07	50.90				
OW-25B	25.92	31.02	50.90	0.0	17.05	0.0	Horizontal
OW-26A	39.05	44.12	54.47				
OW-26B	20.04	25.11	54.41	0.06	19.01	0.003	Downward
OW-27A	28.12	33.19	52.31				
OW-27B	-25.45	-20.37	51.20	1.11	53.56	0.021	Downward
OW-30A	45.18	50.25	53.38				
OW-30B	5.27	10.34	53.24	0.14	39.91	0.004	Downward
OW-33A	10.13	15.23	50.81				
OW-33B	-29.55	-24.47	50.89	-0.08	39.70	0.002	Upward

Notes:

(1) Feet Above Mean Sea Level
(2) Feet Below Land Surface
dh = Difference of Elevation
dl = Distance Between Midpoints of Screen
I_v = Vestical hydraulic gradient

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MO06609Dy.1D.3

Table 3-6. Calculation of Vertical Gradients in Monitoring Well Clusters, Industri-Plex Site, Woburn, Massachusetts.

Well	Elevation Bottom of Screen (1)	Elevation Midpoint of Screen (1)	Water Level July 17, 1990	dh (ft) July 17, 1990	dl (ft) July 17, 1990	I_v July 17, 1990	Direction of Flow July 17, 1990
OW-18	7.30	27.30	53.21				
OW-18A	46.11	51.11	53.19	-.02	23.81	.0008	Upward
OW-19	-12.57	2.43	52.95				
OW-19A	16.19	33.69	52.92	-0.03	31.26	0.001	Upward
OW-24A	32.5	37.57	51.77				
OW-24B	-2.39	2.68	51.67	0.10	34.89	0.003	Downward
OW-25A	43	48.07	50.69				
OW-25B	25.92	31.02	50.69	0.0	17.05	0.0	Horizontal
OW-26A	39.05	44.12	53.93				
OW-26B	20.04	25.11	53.99	-0.06	19.01	0.003	Upward
OW-27A	28.12	33.19	51.96				
OW-27B	-25.45	-20.37	50.96	1.00	53.56	0.019	Downward
OW-30A	45.18	50.25	53.05				
OW-30B	5.27	10.34	52.95	0.10	39.91	0.003	Downward
OW-33A	10.13	15.23	54.56				
OW-33B	-29.55	-24.47	50.56	0.0	39.70	0.0	Horizontal

Notes:
    (1) Feet Above Mean Sea Level
    (2) Feet Below Land Surface
    dh = Difference of Elevation
    dl = Distance Between Midpoints of Screen
    I_v = Vestical hydraulic gradient

ROUX ASSOCIATES INC

Table 3-6.   Calculation of Vertical Gradients in Monitoring Well Clusters, Industri-Plex Site, Woburn, Massachusetts.

Well	Elevation Bottom of Screen (1)	Elevation Midpoint of Screen (1)	Water Level August 13, 1990	dh (ft) August 13, 1990	dl (ft) August 13, 1990	I_v August 13, 1990	Direction of Flow August 13, 1990
OW-18	7.30	27.30	54.40				
OW-18A	46.11	51.11	54.34	-0.06	23.81	.003	Upward
OW-19	-12.57	2.43	52.51				
OW-19A	16.19	33.69	52.50	-0.01	31.26	0.0003	Upward
OW-24A	32.5	37.57	53.40				
OW-24B	-2.39	2.68	53.40	0.0	34.89	0.0	Horizontal
OW-25A	43	48.07	52.58				
OW-25B	25.92	31.02	52.46	0.12	17.05	0.007	Downward
OW-26A	39.05	44.12	55.82				
OW-26B	20.04	25.11	55.89	-0.07	19.01	0.004	Upward
OW-27A	28.12	33.19	54.20				
OW-27B	-25.45	-20.37	52.06	2.14	53.56	0.040	Downward
OW-30A	45.18	50.25	54.11				
OW-30B	5.27	10.34	53.96	0.15	39.91	0.004	Downward
OW-33A	10.13	15.23	52.19				
OW-33B	-29.55	-24.47	52.11	0.08	39.70	0.002	Downward

Notes:

(1) Feet Above Mean Sea Level
(2) Feet Below Land Surface
dh = Difference of Elevation
dl = Distance Between Midpoints of Screen
I_v = Vestical hydraulic gradient

ROUX ASSOCIATES INC

Table 3-6. Calculation of Vertical Gradients in Monitoring Well Clusters, Industri-Plex Site, Woburn, Massachusetts.

Well	Elevation Bottom of Screen (1)	Elevation Midpoint of Screen (1)	Water Level Sept. 26, 1990	dh (ft) Sept. 26, 1990	dl (ft) Sept. 26, 1990	I_v Sept. 26, 1990	Direction of Flow Sept. 26, 1990
OW-18	7.30	27.30	53.31				
OW-18A	46.11	51.11	53.26	-0.05	23.81	0.002	Upward
OW-19	-12.57	2.43	51.22				
OW-19A	16.19	33.69	51.20	-0.02	31.26	0.0006	Upward
OW-24A	32.5	37.57	52.04				
OW-24B	-2.39	2.68	51.96	0.08	34.89	0.002	Downward
OW-25A	43	48.07	50.90				
OW-25B	25.92	31.02	50.91	-0.01	17.05	0.001	Upward
OW-26A	39.05	44.12	54.39				
OW-26B	20.04	25.11	54.49	-0.10	19.01	0.005	Upward
OW-27A	28.12	33.19	52.12				
OW-27B	-25.45	-20.37	51.10	1.07	53.56	0.020	Downward
OW-30A	45.18	50.25	53.10				
OW-30B	5.27	10.34	53.10	0.0	39.91	0.0	Horizontal
OW-33A	10.13	15.23	50.84				
OW-33B	-29.55	-24.47	50.73	0.11	39.70	0.003	Downward

Notes:
(1) Feet Above Mean Sea Level
(2) Feet Below Land Surface
dh = Difference of Elevation
dl = Distance Between Midpoints of Screen
I_v = Vestical hydraulic gradient

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Table 3-6.   Calculation of Vertical Gradients in Monitoring Well Clusters, Industri-Plex Site, Woburn, Massachusetts.

Well	Elevation Bottom of Screen (1)	Elevation Midpoint of Screen (1)	Water Level Dec. 7, 1990	dh (ft) Dec. 7, 1990	dl (ft) Dec. 7, 1990	I_v Dec. 7, 1990	Direction of Flow Dec. 7, 1990
OW-18	7.30	27.30	54.00				
OW-18A	46.11	51.11	54.26	0.26	23.81	0.011	Downward
OW-19	-12.57	2.43	51.92				
OW-19A	16.19	33.69	51.91	-0.01	31.26	0.0003	Upward
OW-24A	32.5	37.57	51.78				
OW-24B	-2.39	2.68	56.70	-0.92	34.89	0.026	Upward
OW-25A	43	48.07	51.73				
OW-25B	25.92	31.02	51.70	0.03	17.05	0.002	Downward
OW-26A	39.05	44.12	55.31				
OW-26B	20.04	25.11	55.26	0.05	19.01	0.003	Downward
OW-27A	28.12	33.19	52.73				
OW-27B	-25.45	-20.37	51.54	1.19	53.56	0.022	Downward
OW-30A	45.18	50.25	53.70				
OW-30B	5.27	10.34	53.55	0.15	39.91	0.004	Downward
OW-33A	10.13	15.23	51.52				
OW-33B	-29.55	-24.47	51.53	-0.01	39.70	<0.001	Upward

Notes: (1) Feet Above Mean Sea Level
(2) Feet Below Land Surface
dh = Difference of Elevation
dl = Distance Between Midpoints of Screen
I_v = Vestical hydraulic gradient

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MO06609Dy.1D.3

Table 3-6.   Calculation of Vertical Gradients in Monitoring Well Clusters, Industri-Plex Site, Woburn, Massachusetts.

Well	Elevation Bottom of Screen (1)	Elevation Midpoint of Screen (1)	Water Level Feb. 26, 1991	dh (ft) Feb. 26, 1991	dl (ft) Feb. 26, 1991	I_v Feb. 26, 1991	Direction of Flow Feb. 26, 1991
OW-18	7.30	27.30	54.03				
OW-18A	46.11	51.11	54.03	0.0	23.81	0.0	Horizontal
OW-19	-12.57	2.43	51.78				
OW-19A	16.19	33.69	51.77	-0.01	31.26	0.0003	Upward
OW-24A	32.5	37.57	52.70				
OW-24B	-2.39	2.68	52.59	0.11	34.89	0.003	Downward
OW-25A	43	48.07	51.56				
OW-25B	25.92	31.02	51.55	0.01	17.05	0.001	Downward
OW-26A	39.05	44.12	55.40				
OW-26B	20.04	25.11	55.32	0.08	19.01	0.004	Downward
OW-27A	28.12	33.19	52.65				
OW-27B	-25.45	-20.37	51.61	1.04	53.56	0.019	Downward
OW-30A	45.18	50.25	53.72				
OW-30B	5.27	10.34	53.61	0.11	39.91	0.003	Downward
OW-33A	10.13	15.23	51.43				
OW-33B	-29.55	-24.47	51.43	0.0	39.70	0.0	Horizontal

Notes: (1) Feet Above Mean Sea Level
                (2) Feet Below Land Surface
                dh = Difference of Elevation
                dl = Distance Between Midpoints of Screen
                I_v = Vertical hydraulic gradient

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MO06609Dy.1D.3

Table 3-6.   Calculation of Vertical Gradients in Monitoring Well Clusters, Industri-Plex Site, Woburn, Massachusetts.

Well	Elevation Bottom of Screen (1)	Elevation Midpoint of Screen (1)	Water Level April 17-19, 1991	dh (ft) April 17-19, 1991	dl (ft) April 17-19, 1991	I$_v$ April 17-19, 1991	Direction of Flow April 17-19, 1991
OW-18	7.30	27.30	53.67				
OW-18A	46.11	51.11	53.67	0	23.81	0	Horizontal
OW-19	-12.57	2.43	51.53				
OW-19A	16.19	33.69	51.54	0.01	31.26	0.0003	Downward
OW-24A	32.5	37.57	52.38				
OW-24B	-2.39	2.68	52.24	0.14	34.89	0.004	Downward
OW-25A	43	48.07	51.52				
OW-25B	25.92	31.02	51.31	0.21	17.05	0.012	Downward
OW-26A	39.05	44.12	54.93				
OW-26B	20.04	25.11	54.91	0.02	19.01	0.001	Downward
OW-27A	28.12	33.19	52.27				
OW-27B	-25.45	-20.37	51.35	0.92	53.56	0.017	Downward
OW-30A	45.18	50.25	53.41				
OW-30B	5.27	10.34	53.33	0.08	39.91	0.002	Downward
OW-33A	10.13	15.23	51.11				
OW-33B	-29.55	-24.47	51.16	-0.05	39.70	0.001	Upward

Notes:

(1) Feet Above Mean Sea Level
(2) Feet Below Land Surface
dh = Difference of Elevation
dl = Distance Between Midpoints of Screen
I$_v$ = Vestical hydraulic gradient

ROUX ASSOCIATES INC

MO06609Dy.1D.3

Table 3-6. Calculation of Vertical Gradients in Monitoring Well Clusters, Industri-Plex Site, Woburn, Massachusetts.

Well	Elevation Bottom of Screen (1)	Elevation Midpoint of Screen (1)	Water Level May 13, 1991	dh (ft) May 13, 1991	dl (ft) May 13, 1991	I$_v$ May 13, 1991	Direction of Flow May 13, 1991
OW-18	7.30	27.30	53.89				
OW-18A	46.11	51.11	53.84	-0.05	23.81	0.002	Upward
OW-19	-12.57	2.43	51.65				
OW-19A	16.19	33.69	51.63	-0.02	31.26	0.0006	Upward
OW-24A	32.5	37.57	52.54				
OW-24B	-2.39	2.68	52.29	0.25	34.89	0.007	Downward
OW-25A	43	48.07	51.39				
OW-25B	25.92	31.02	51.39	0.0	17.05	0.0	Horizontal
OW-26A	39.05	44.12	55.33				
OW-26B	20.04	25.11	55.26	0.07	19.01	0.004	Downward
OW-27A	28.12	33.19	52.47				
OW-27B	-25.45	-20.37	51.60	0.87	53.56	0.016	Downward
OW-30A	45.18	50.25	53.63				
OW-30B	5.27	10.34	53.46	0.17	39.91	0.004	Downward
OW-33A	10.13	15.23	51.23				
OW-33B	-29.55	-24.47	51.28	-0.05	39.70	0.001	Upward

Notes:

(1) Feet Above Mean Sea Level
(2) Feet Below Land Surface
dh = Difference of Elevation
dl = Distance Between Midpoints of Screen
I$_v$ = Vestical hydraulic gradient

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Table 3-7.   Ground-Water Sample Field Measurements at the Industri-Plex Site, Woburn, Massachusetts.

Well Number	Date/Time of Measurement	Water Color or Tint	Turbidity	Temperature In Situ (°C)	pH	Conductivity (μmhos/cm)	Eh (mV)
OW-12	3-15-90/1100 hrs.	tan	low	9.5	7.15	4,200	-91.7
OW-14	3-15-90/1215 hrs.	orange	moderate	8.5	5.87	520	+178.4
OW-18A	3-15-90/1350 hrs.	orange	moderate	10	6.27	860	+207.0
OW-17	3-15-90/1505 hrs.	brown	low	9.5	7.01	5,670	-85.0
OW-18	3-15-90/1635 hrs.	none	clear	10.5	5.65	1,020	+191.7
OW-6	3-16-90/0945 hrs.	tan	low	7.5	6.36	540	+170.2
OW-20	3-16-90/1310 hrs.	black	low	10	6.83	420	-164.0
OW-19A	3-16-90/1515 hrs.	tan	low	8.5	6.47	340	+78.7
OW-19	3-16-90/1700 hrs.	tan	moderate	9	6.01	440	+120.8
OW-4	3-19-90/0950 hrs.	orange	moderate	9	6.95	960	+30.4
OW-15	3-19-90/1055 hrs.	none	low	6.5	6.07	550	+137.5
OW-9	3-19-90/1345 hrs.	green-black	high	11	7.38	920	-174.5
OW-13	3-19-90/1510 hrs.	gray	moderate	12	7.02	990	-141.5
OW-1A	3-19-90/1730 hrs.	tan	moderate	4.5	6.56	210	+104.7
OW-1	3-20-90/1030 hrs.	none	clear	10	6.67	1,210	+57.0
OW-10	3-20-90/1200 hrs.	tan	low	8	5.34	220	+243.1
OW-11	3-20-90/1420 hrs.	orange	moderate	7	6.39	340	+50.3
OW-16	3-20-90/1530 hrs.	brown	low	9	7.80	17,880	-59.2
OW-21	3-21-90/1040 hrs.	gray	low	6.5	5.95	360	+113.0
OW-22	3-21-90/1240 hrs.	gray	moderate	6.5	6.34	1,900	-25.6
OW-28	3-21-90/1400 hrs.	brown	high	9	6.60	190	+128.2
OW-7	4-25-90/1500 hrs.	tan	moderate	10	6.17	470	+202.2

Table 3-8.   Organic Compounds Detected in Upgradient and On-Site Monitoring Wells, Industri-Plex Site, Woburn, Massachusetts.

1.   Upgradient

Volatile Organic Compounds

chloroform
toluene

Semi-Volatile Compounds

bis(2-Ethylhexyl)phthalate

2.   On-Site

Volatile Organic Compounds

acetone
benzene
chloroform
ethylbenzene
methylene chloride
toluene
xylenes

Semi-Volatile Compounds

benzoic acid
bis(2-ethylhexyl)phthalate
1,2 dichlorobenzene
2-methylphenol
4-methylphenol
n-nitrosodiphenylamine
phenol

Table 3-9.   Organic Compounds Detected in Downgradient (Off-Site) Monitoring Wells, Industri-Plex Site, Woburn, Massachusetts.

Volatile Organic Compounds

        benzene
        chloroform
        1,1-dichloroethane
        1,2-dichloroethane
        1,1-dichloroethene
        1,2-dichloroethene
        methylene chloride
        toluene
        1,1,1,-trichoroethane
        trans-1,2-dichloroethene
        trichloroethene
        xylenes

Semi-Volatile Organic Compounds

        ancenaphthene
        1,3-dichlorbenzene
        diethylphthalate
        phenol

Table 3-10. Surface-Water Sampling Locations at the Industri-Plex Site, Woburn, Massachusetts.

Sampling Location	Description of Sampling Location
SW-1	North end of South Pond near flood retention dam
SW-2	West branch of the Aberjona River
SW-3	I-93 Drainway
SW-4	Northern branch of the Aberjona River
SW-5	Channeled section of the Aberjona River
SW-6	Unnamed Tributary
SW-7	New Boston Street Drainway
SW-8	I-93 Drainway and Phillips Pond
SW-9	North end of Hall's Brook Holding Area
SW-10	Hall's Brook near railroad tracks
SW-11	Center of Hall's Brook Holding Area
SW-12	Channeled section of Aberjona River west of Commerce Way
SW-13	Discharge of Hall's Brook Holding Area
SW-14	Hall's Brook Holding Area and Aberjona River Confluence
SW-15	New Boston St. Drainway
SW-16	Atlantic Avenue Drainway
SW-17	Confluence of west branch and northern branch of Aberjona River

Table 3-11.   Surface-Water Elevation Data at the Industri-Plex Site, Woburn, Massachusetts.

		April 10, 1990			May 30, 1990		
Staff Gauge Designation	Elevation of Measuring Point (ft above mean sea level)	Depth of Surface Water (feet)	Depth to Water from Measuring Point* (ft below measuring point)	Elevation of Water Table (ft above mean sea level)	Depth of Surface Water (feet)	Depth to Water from Measuring Point* (ft below measuring point)	Elevation of Water Table (ft above mean sea level)
SW-1	72.44	--	--	--	1.44	1.86	70.58
SW-3	71.695	0.44	2.86	68.835	0.47	2.83	68.865
SW-7	71.725	0.78	2.52	69.205	1.60	1.70	70.025
SW-14	50.305	0.85	2.45	47.855	1.35	1.95	48.355
Telog Location (1)	64.53	1.81	1.49	63.04	2.62	0.68	63.85

		June 20, 1990			June 26, 1990		
Staff Gauge Designation	Elevation of Measuring Point (ft above mean sea level)	Depth of Surface Water (feet)	Depth to Water from Measuring Point* (ft below measuring point)	Elevation of Water Table (ft above mean sea level)	Depth of Surface Water (feet)	Depth to Water from Measuring Point* (ft below measuring point)	Elevation of Water Table (ft above mean sea level)
SW-1	72.44	0.66	2.64	68.48	0.60	2.70	69.74
SW-3	71.695	0.40	2.90	68.795	0.48	2.82	68.875
SW-7	71.725	0.76	2.54	69.185	0.54	2.76	68.965
SW-14	50.305	0.65	2.65	47.655	0.56	2.74	47.565
Telog Location (1)	64.53	1.37	1.93	62.60	1.00	2.30	62.23

NOTES:
 * Measuring Point at 3.30 ft mark on staff gauge.
 (1) Staff gauge located within Aberjona River adjacent to PZ-1 and PZ-2.

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Table 3-11.   Surface-Water Elevation Data at the Industri-Plex Site, Woburn, Massachusetts.

Staff Gauge Designation	Elevation of Measuring Point (ft above mean sea level)	July 17, 1990			August 13, 1990		
		Depth of Surface Water (feet)	Depth to Water from Measuring Point* (ft below measuring point)	Elevation of Water Table (ft above mean sea level)	Depth of Surface Water (feet)	Depth to Water from Measuring Point* (ft below measuring point)	Elevation of Water Table (ft above mean sea level)
SW-1	72.44	0.50	2.80	69.64	1.06	2.24	70.20
SW-3	71.695	0.38	2.92	68.775	0.40	2.90	68.80
SW-7	71.725	0.42	2.88	68.845	0.56	2.74	68.99
SW-14	50.305	0.52	2.78	47.525	1.05	2.25	48.06
Telog Location (1)	64.53	0.58	2.72	61.81	1.95	1.35	63.18

Staff Gauge Designation	Elevation of Measuring Point (ft above mean sea level)	September 26, 1990			December 7, 1990		
		Depth of Surface Water (feet)	Depth to Water from Measuring Point* (ft below measuring point)	Elevation of Water Table (ft above mean sea level)	Depth of Surface Water (feet)	Depth to Water from Measuring Point* (ft below measuring point)	Elevation of Water Table (ft above mean sea level)
SW-1	72.44	0.65	2.65	69.79	1.74	1.56	70.88
SW-3	71.695	dry	--	--	0.41	2.89	68.805
SW-7	71.725	0.46	2.84	68.885	0.58	2.72	69.005
SW-14	50.305	0.56	2.74	47.565	0.80	2.50	47.805
Telog Location (1)	64.53	1.15	2.15	62.38	1.48	1.82	62.71

NOTES:
 * Measuring Point at 3.30 ft mark on staff gauge.
(1) Staff gauge located within Aberjona River adjacent to PZ-1 and PZ-2.

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Table 3-11. Surface-Water Elevation Data at the Industri-Plex Site, Woburn, Massachusetts.

Staff Gauge Designation	Elevation of Measuring Point (ft above mean sea level)	February 26, 1991			May 13, 1991		
		Depth of Surface Water (feet)	Depth to Water from Measuring Point* (ft below measuring point)	Elevation of Water Table (ft above mean sea level)	Depth of Surface Water (feet)	Depth to Water from Measuring Point* (ft below measuring point)	Elevation of Water Table (ft above mean sea level)
SW-1	72.44	2.42	0.88	71.56	1.00	2.30	70.14
SW-3	71.695	0.40	2.90	68.795	0.42	2.90	68.795
SW-7	71.725	0.55	2.75	68.975	0.88	2.42	69.305
SW-14	50.305	0.78	2.52	47.785	0.70	2.60	47.705
Telog Location (1)	64.53	1.76	1.54	62.99	1.40	1.90	62.63

NOTES:
 * Measuring Point at 3.30 ft mark on staff gauge.
(1) Staff gauge located within Aberjona River adjacent to PZ-1 and PZ-2.

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Table 3-12. Surface-Water Discharge Measurements at the Industri-Plex Site, Woburn, Massachusetts.

Measurement Location	April 19, 1990 High Flow		June 20, 1990		July 17, 1990	
	Average Velocity (ft/second)	Discharge (CFS)	Average Velocity (ft/second)	Discharge (CFS)	Average Velocity (ft/second)	Discharge (CFS)
SW-1	0.10	0.63	NM	NM	NM	NM
SW-2	0.13	0.17	NM	0.15 (T)	NM	0.0034 (T)
SW-3	0.01	0.001	NM	NM	NM	NM
SW-4	0.20	0.62	NM	NM	NM	NM
SW-5	0.97	5.53	0.71	2.38	0.07	<0.057
SW-6	0.03	0.15	NM	NM	NM	NM
SW-7	0.25	0.72	NM	NM	NM	NM
SW-8	0.11	0.09	NM	NM	NM	NM
SW-9	0.02 (1)	24.68 (1)	NM	NM	NM	NM
SW-10	1.80	8.08	0.67	2.37	0.23	0.60
SW-11	0.01 (1)	18.88 (1)	NM	NM	NM	NM
SW-12	0.03	0.41 (2)	0.22	1.16	<0.01	<0.034
SW-13	0.26	5.49	NM	NM	NM	NM
SW-14	0.79	9.86	0.58	4.02	0.19	1.20
SW-15	0.29	0.99	NM	NM	NM	NM
SW-16	0.0	0.0	NM	NM	NM	NM
SW-17	0.03	0.21 (2)	0.13	0.36	<0.01	<0.004

NOTES:
CFS   Cubic feet per second
(1)   Measurement taken from a boat; therefore measurement was influenced by the movement of the boat.
(2)   Data not considered representative due to equipment problems.
(T)   Timed bucket measurement.
NM   Not measured; not required by GSIP Work Plan.

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Table 3-12. Surface-Water Discharge Measurements at the Industri-Plex Site,
            Woburn, Massachusetts.

Measurement Location	July 31-August 3, 1990 Low Flow		August 21, 1990		September 26, 1990	
	Average Velocity (ft/second)	Discharge (CFS)	Average Velocity (ft/second)	Discharge (CFS)	Average Velocity (ft/second)	Discharge (CFS)
SW-1	<0.01	<0.011	NM	NM	NM	NM
SW-2	<0.01	<0.0023	NM	0.35 (T)	NM	0.16 (T)
SW-3	dry	dry	NM	NM	NM	NM
SW-4	0.43	0.012	NM	NM	NM	NM
SW-5	0.50	0.72	0.43	1.84	0.16	0.53
SW-6	0.22	0.50	NM	NM	NM	NM
SW-7	0.17	0.29	NM	NM	NM	NM
SW-8	dry	dry	NM	NM	NM	NM
SW-9	0.11 (1)	152 (1)	NM	NM	NM	NM
SW-10	0.72	2.11	0.71	2.54	0.35	1.10
SW-11	0.06 (1)	106 (1)	NM	NM	NM	NM
SW-12	0.20	0.60	0.33	2.21	0.09	0.52
SW-13	0.18	2.18	NM	NM	NM	NM
SW-14	0.54	4.27	0.67	5.89	0.32	2.50
SW-15	0.23	0.93	NM	NM	NM	NM
SW-16	dry	dry	NM	NM	NM	NM
SW-17	<0.06	<0.08	0.22	0.67	0.15	0.30

NOTES:
CFS   Cubic feet per second
(1)   Measurement taken from a boat; therefore measurement was influenced by the movement
       of the boat.
(2)   Data not considered representative due to equipment problems.
(T)   Timed bucket measurement.
NM   Not measured; not required by GSIP Work Plan.

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Table 3-13.   Surface-Water Low Flow Sampling Field Measurements at the Industri-Plex Site, Woburn, Massachusetts.

Sampling Location/Designation	Date/Time of Measurement	Temperature (°C)	pH	Conductivity (μmhos/cm)	Eh (mV)	Dissolved O₂ (mg/L)
SW-1	8-03-90/0950 hrs.	24	7.63	220	+178.1	7.3
SW-2	8-03-90/0830 hrs.	20	NA	310	+13.9	3.2
SW-3	8-03-90/1425 hrs.	--	--	--	--	--
SW-4	8-02-90/1730 hrs.	27	6.35	540	+130.0	7.3
SW-5	8-02-90/1315 hrs.	24	6.55	400	+119.9	4.9
SW-6	8-02-90/0750 hrs.	10	7.57	1040	-1.4	5.0
SW-7	8-01-90/1800 hrs.	23	7.62	1180	+111.7	6.2
SW-8	8-03-90/1145 hrs.	25	7.90	280	+169.0	10.2
SW-9	8-01-90/0930 hrs.	21	9.75	540	+155.3	4.9
SW-10	8-01-90/1300 hrs.	22	7.03	600	+139.2	6.2
SW-11	7-31-90/1545 hrs.	27	9.92	470	+198.1	7.4
SW-12	8-02-90/1100 hrs.	19	5.61	400	+129.4	3.6
SW-13	7-31-90/1330 hrs.	27	6.79	460	+213.0	7.3
SW-14	7-31-90/0930 hrs.	21	6.07	450	+120.2	6.5
SW-15	8-01-90/1445 hrs.	23	9.89	1180	+120.7	6.1
SW-16	8-02-90/1000 hrs.	--	--	--	--	--
SW-17	8-02-90/1650 hrs.	26	6.70	480	+39.9	**

--   Surface-water sampling location was dry; no sample collected.
**   No measurement taken due to instrument malfunction.
NA   No data available.

Table 3-14. Stream Sediment Low Flow Sampling Field Measurements at the Industri-Plex Site, Woburn, Massachusetts.

Sampling Location	Sample Designation	Date/Time of Measurement	pH (1)	Eh (mV)
SW-1	SED-1	8-03-90/0950 hrs.	7.0	-226.4
SW-2	SED-2	8-03-90/0830 hrs.	6.4	-184.9
SW-3	SED-3	8-03-90/1425 hrs.	5.8	+108.4
SW-4	SED-4	8-02-90/1730 hrs.	7.5	+135.6
SW-5	SED-5	8-02-90/1315 hrs.	6.9	+23.5
SW-6	SED-6	8-02-90/0750 hrs.	7.9	-241.9
SW-7	SED-7	8-01-90/1800 hrs.	6.7	-1.5
SW-8	SED-8	8-03-90/1145 hrs.	6.0	+347.1
SW-9	SED-9	8-01-90/0930 hrs.	7.4	-239.9
SW-10	SED-10	8-01-90/1300 hrs.	7.1	+129.4
SW-11	SED-11	7-31-90/1545 hrs.	7.0	-204.7
SW-12	SED-12	8-02-90/1100 hrs.	6.8	+41.7
SW-13	SED-13	7-31-90/1330 hrs.	7.1	-205.1
SW-14	SED-14	7-31-90/0930 hrs.	6.9	-24.1
SW-15	SED-15	8-01-90/1445 hrs.	7.3	+205.4
SW-16	SED-16	8-02-90/1000 hrs.	6.7	-193.4
SW-17	SED-17	8-02-90/1650 hrs.	7.5	-178.3
South of SW-13	CORE-1	8-03-90	5.6	+61.9

(1)   laboratory measurement

Table 3-15. Concentrations of Total Suspended Solids and Surface Water Discharge Estimates at SW-3, SW-7 and SW-14, Industri-Plex Site, Woburn, Massachusetts.

Station	April 19, 1990 (High Flow)			July 31-August 3, 1990 (Low Flow)		
	Total Suspended Solids (mg/L)	Discharge (CFS)	Volume (lbs/day)	Total Suspended Solids (mg/L)	Discharge (CFS)	Volume (lbs/day)
SW-3	8.5	0.001	0.45	dry	0	0
SW-7	5.0	0.72	19.41	7.0	0.29	10.94
SW-14	<5.0	9.86	<265.00	9.0	4.27	207.00

CFS - Cubic feet per second.
mg/L - Concentration in milligrams per liter.

Table 3-16. Calculated Volumes of Suspended Sediment Discharge
During Low Flow Conditions, Industri-Plex Site,
Woburn, Massachusetts.

Station	Total Suspended Solids (mg/L)	Discharge (August, 1990 in CFS)	Volume of Suspended Sediment (lbs/day)
SW-1	<5.0	<0.011	<0.290
SW-2	6.0	<0.002	<0.06
SW-3	dry	dry	0
SW-4	5.0	0.012	0.324
SW-5	<5.0	0.72	<19.41
SW-6	18.0	0.50	48.53
SW-7	7.0	0.29	10.94
SW-8	dry	dry	0
SW-9	<5.0	(1)	(1)
SW-10	<5.0	2.11	<56.89
SW-11	<5.0	(1)	(1)
SW-12	<5.0	0.60	<16.17
SW-13	<5.0	2.18	<58.77
SW-14	9.0	4.27	207.0
SW-15	9.0	0.93	45.13
SW-16	dry	dry	0
SW-17	7.0	<0.08	<3.01

NOTE:

(1) Measurement not considered representative.

Table 3-17. Organic Compounds Detected in Aberjona River Surface-Water Samples, Collected During July 31, 1990 to August 3, 1990 at the Industri-Plex Site, Woburn, Massachusetts.

Upstream Site Boundary

	SW-1
Di-n-butylphthalate, filtered	3 µg/L

On-Site

	SW-2	SW-4	SW-8	SW-17
Acetone	20 µg/L		3 µg/L	
Methylene chloride		2 µg/L		
Di-n-butylphthalate, filtered	2 µg/L	4 µg/L	1 µg/L	6 µg/L

Downstream

	SW-14	SW-5	SW-12
Methylene chloride	8 µg/L		
Bis (2-Ethylhexyl)phthalate, unfiltered	1 µg/L		
Diethylphthalate, unfiltered	3 µg/L		
Diethylphthalate, filtered	2 µg/L		
Di-n-butylphthalate, unfiltered	1 µg/L		
Di-n-butylphthalate, filtered	4 µg/L	7 µg/L	20 µg/L
N-Nitrosodiphenylamine, unfiltered	1 µg/L		
N-Nitrosodiphenylamine, filtered	1 µg/L		

Table 3-18. Organic Compounds Detected in Hall's Brook Surface-Water Samples Collected During July 31, 1990 to August 3, 1990 at the Industri-Plex Site, Woburn, Massachusetts.

Upstream Site Boundary

	SW-6
Chlorobenzene	2 µg/L
1,2-Dichloroethene, total	
Methylene chloride	
Toluene	
Trichloroethene	
Bis (2-Ethylhexyl) phthalate, filtered	
Bis (2-Ethylhexyl) phthalate, unfiltered	
Di-n-butylphthalate, filtered	3 µg/L
Phenol, filtered	

On-Site

	SED-7	SW-15	SW-10
Chlorobenzene			1 µg/L
1,2-Dichloroethene, total	6 µg/L		
Methylene chloride	7 µg/L	7 µg/L	7 µg/L
Toluene	2 µg/L		2 µg/L
Trichloroethene	6 µg/L		3 µg/L
Bis (2-Ethylhexyl) phthalate, filtered	1 µg/L		
Bis (2-Ethylhexyl) phthalate, unfiltered	2 µg/L	4 µg/L	5 µg/L
Di-n-butylphthalate, filtered	3 µg/L		4 µg/L
Phenol, filtered	1 µg/L		

Table 3-18. Organic Compounds Detected in Hall's Brook Surface-Water Samples Collected During July 31, 1990 to August 3, 1990 at the Industri-Plex Site, Woburn, Massachusetts.

Downstream

	SW-9	SW-11	SW-13	SW-14
1,1,-Dichloroethane	3 µg/L	3 µg/L	8 µg/L	1 µg/L
1,2-Dichloroethene, total	11 µg/L	2 µg/L	2 µg/L	
Methylene chloride	7 µg/L	8 µg/L	8 µg/L	8 µg/L
1,1,1-Trichloroethane		4 µg/L	9 µg/L	
Trichloroethene	11 µg/L	3 µg/L		
Xylenes, total		1 µg/L		
Bis (2-Ethylhexyl) phthalate, unfiltered		12 µg/L		1 µg/L
Bis (2-Ethylhexyl) phthalate, filtered	3 µg/L			
Butylbenzylphthalate, unfiltered		2 µg/L		
Diethylphthalate, unfiltered		3 µg/L	3 µg/L	3 µg/L
Diethylphthalate, filtered		3 µg/L	2 µg/L	2 µg/L
Di-n-butylphthalate, unfiltered				1 µg/L
Di-n-butylphthalate, filtered	5 µg/L	11 µg/L	6 µg/L	4 µg/L
N-Nitrosodiphenylamine, unfiltered		1 µg/L		1 µg/L
N-Nitrosodiphenylamine, filtered	1 µg/L	1 µg/L		1 µg/L

Table 3-19. Summary of Stream Sediment Grain Size Data During Low Flow
Conditions, Industri-Plex Site, Woburn, Massachusetts.

Station	Location	Percent Gravel	Percent Sand	Percent Silt/Clay
SW-1	South Pond	44	52	4
SW-2	Aberjona	2	95	3
SW-3	I-93 Drainway	4	84	12
SW-4	Aberjona River	25	72	3
SW-5	Aberjona River	2	96	2
SW-6	Unnamed Tributary	1	53	46
SW-7	New Boston St. Drainway	28	59	13
SW-8	I-93 Drainway	0	98	2
SW-9	Hall's Brook Holding Area	0	5	95
SW-10	Hall's Brook	4	95	1
SW-11	Hall's Brook Holding Area	0	0	100
SW-12	Aberjona River	1	97	2
SW-13	Hall's Brook	0	13	87
SW-14	Aberjona River	1	98	1
SW-15	New Boston St. Drainway	3	93	4
SW-16	Atlantic Ave. Drainway	18	42	40
SW-17	Aberjona River	25	71	4
Core 1 0.2-0.5 ft.	Hall's Brook	0	96	4

Table 3-20. Organic Compounds Detected in Aberjona River Stream Sediments Collected During July 31, 1990 to August 3, 1990 at the Industri-Plex Site, Woburn, Massachusetts. Page 1 of 2

Upstream Site Boundary

	SED-1	SED-3
Methylene chloride	7 µg/kg	7 µg/kg
Toluene	6 µg/kg	
Bis (2-Ethylhexyl) phthalate	160 µg/kg	

On-Site

	SED-2	SED-4	SED-17	SED-8
Acetone			22 µg/kg	
Methylene chloride	6 µg/kg	5 µg/kg	4 µg/kg	7 µg/kg
Anthracene	320 µg/kg			
Benzo (a) anthracene	870 µg/kg			
Benzo (a) pyrene	600 µg/kg			
Benzo (b) fluorene	1000 µg/kg		140 µg/kg	
Benzo (g,h,i) perylene	350 µg/kg			
Benzo (k) fluoranthene	1000 µg/kg		140 µg/kg	
Chrysene	880 µg/kg			
Fluoranthene	1500 µg/kg		130 µg/kg	
Indeno (1,2,3-cd) pyrene	410 µg/kg			
Phenanthrene	990 µg/kg			
Pyrene	1500 µg/kg		120 µg/kg	
Benzoic acid			1300 µg/kg	
Bis (2-Ethylhexyl) phthalate			110 µg/kg	

Downstream

	SED-5	SED-12	SED-14
2-Hexanone	9 µg/kg		
Methylene chloride	4 µg/kg	4 µg/kg	2 µg/kg
4-Methyl-2-Pentanone	2 µg/kg		
Tetrachloroethene		3 µg/kg	
Trichloroethene		2 µg/kg	
Anthracene	200 µg/kg	2900 µg/kg	
Benzo (a) anthracene	770 µg/kg	11000 µg/kg	480 µg/kg
Benzo (a) pyrene	770 µg/kg	9900 µg/kg	410 µg/kg
Benzo (b) fluoranthene	1900 µg/kg	21000 µg/kg	340 µg/kg
Benzo (g,h,i) perylene	310 µg/kg	4200 µg/kg	290 µg/kg
Benzo (k) fluoranthene	1900 µg/kg	21000 µg/kg	340 µg/kg
Bis (2-Ethylhexyl) phthalate	320 µg/kg	1300 µg/kg	630 µg/kg
Chrysene	1100 µg/kg	13000 µg/kg	630 µg/kg
Fluoranthene	1600 µg/kg	24000 µg/kg	1300µg/kg
Indeno (1,2,3-cd) pyrene	330 µg/kg	4200 µg/kg	290 µg/kg
Phenanthrene	910 µg/kg	17000 µg/kg	360 µg/kg
Pyrene	1500 µg/kg	22000 µg/kg	1100µg/kg
Dibenzo (a,h) anthracene		2600 µg/kg	1100 µg/kg
Dibenzofuran		540 µg/kg	
2,4-dinitrotoluene		2900 µg/kg	
Butylbenzylphthalate			1600 µg/kg
3,3'-Dichlorobenzidine			3300 µg/kg

<u>Upstream Site Boundary</u>

	SED-6
Acetone	230 μg/kg
Chlorobenzene	440 μg/kg
Toluene	250 μg/kg
1,2-Dichloroethylene	
Trichloroethene	
Bis (2-Ethylhexyl) phthalate	7900 μg/kg
Fluoranthene	1200 μg/kg
Phenanthrene	1000 μg/kg
Pyrene	1200 μg/kg

On-Site

	SED-7	SED-15	SED-10	SED-16
Acetone				170 µg/kg
1,2-Dichloroethylene	2 µg/kg			
Methylene chloride		6 µg/kg	3 µg/kg	
Tetrachloroethene		11 µg/kg	2 µg/kg	
Trichloroethene	3 µg/kg	3 µg/kg		
Acenaphthylene		180 µg/kg		
Anthracene		770 µg/kg		1700 µg/kg
Benzo (a) anthracene		1200 µg/kg		15000 µg/kg
Benzo (a) pyrene		860 µg/kg		12000 µg/kg
Benzo (b) fluoranthene		1600 µg/kg		27000 µg/kg
Benzo (g,h,i) perylene		310 µg/kg		5700 µg/kg
Benzo (k) fluoranthene		1600 µg/kg		27000 µg/kg
Bis (2-ethylhexyl) phthalate	94000 µg/kg	5200 µg/kg	290 µg/kg	3500 µg/kg
Chrysene		1200 µg/kg		13000 µg/kg
Dibenzo (a,b) anthracene		120 µg/kg		3100 µg/kg
Dibenzofuran		170 µg/kg		
Fluoranthene		2800 µg/kg		22000 µg/kg
Fluorene		240 µg/kg		
Indeno (1,2,3-cd) pyrene		410 µg/kg		5800 µg/kg
N-Nitrosodiphenylamine		100 µg/kg		
Phenanthrene		3200 µg/kg		9900 µg/kg
Pyrene		2300 µg/kg		22000 µg/kg

<u>Downstream</u>

	SED-9	SED-11	SED-13	CORE-1 0.5'-0.9'	SED-14
Acetone		470 µg/kg	400 µg/kg		
Benzene	2100 µg/kg	160 µg/kg	200 µg/kg		
2-Butanone		47 µg/kg	71 µg/kg		
1,2-Dichloroethane	28 µg/kg				
Ethylbenzene	40 µg/kg		39 µg/kg		
Methylene chloride			39 µg/kg		2 µg/kg
Total Xylenes	150 µg/kg				
Anthracene		1500 µg/kg			
Benzo (a) anthracene		2900 µg/kg	1200 µg/kg		480 µg/kg
Benzo (a) pyrene		2700 µg/kg	1000 µg/kg		410 µg/kg
Benzo (b) fluoranthene		2400 µg/kg	1100 µg/kg		340 µg/kg
Benzo (g,h,i) perylene		1900 µg/kg			290 µg/kg
Benzo (k) fluoranthene		2400 µg/kg	1200 µg/kg		340 µg/kg
Bis (2-Ethylhexyl) phthalate		78000 µg/kg	29000 µg/kg	230 µg/kg	360 µg/kg
Chrysene		4500 µg/kg	1800 µg/kg		630 µg/kg
Diethylphthalate		2100 µg/kg	1900 µg/kg		
Fluoranthene		8300 µg/kg	3200 µg/kg		1300 µg/kg
Indeno (1,2,3-cd) pyrene		1900 µg/kg			290 µg/kg
Phenanthrene		7100 µg/kg	2800 µg/kg		360 µg/kg
Pyrene		6600 µg/kg	2600 µg/kg		1100 µg/kg
Butylbenzylphthalate					1600 µg/kg
3,3'-Dichlorobenzidine					3300 µg/kg

Table 3-22. Concentrations of Arsenic and Semi-Volatile Organic Compounds in Stream-Sediments, Industri-Plex Site, Woburn, Massachusetts.

GSIP Sampling Locations	Location	Arsenic (mg/kg)	Semi-Volatile Organic Compounds (mg/kg)	PDI [2] Sampling Locations	Location	Arsenic (mg/kg)
SW-1	South Pond	4.8	0.16	3	New Boston St. Drainway	122.9
SW-2	Aberjona River	371.0	9.42	4	New Boston St. Drainway	245.3
SW-3	I-93 Drainway	28.4	0	5	New Boston St. Drainway	259.0
SW-4	Aberjona River	4.2	3.10	6	New Boston St. Drainway	232.0
SW-5	Aberjona River	12.5	11.61	12	Atlantic Avenue Drainway	8.4
SW-6	Unnamed Tributary	154.0	11.3	13	Atlantic Avenue Drainway	602.7
SW-7	New Boston St. Drainway	1.58	94.0	14	Atlantic Avenue Drainway	73.1
SW-8	I-93 Drainway	2.6	0	15	Atlantic Avenue Drainway	37.2
SW-9	Hall's Brook Holding Area	9,830.0	[1]	16	Atlantic Avenue Drainway	3,453.3
SW-10	Hall's Brook	170.0	.29	17	Atlantic Avenue Drainway	412.3
SW-11	Hall's Brook Holding Area	1,750.0	122.3	18	Aberjona River	16.3
SW-12	Aberjona River	9.4	157.54	19	Aberjona River	171.6
SW-13	Hall's Brook	1,330.0	45.8	20	Aberjona River	90.2
SW-14	Aberjona River	20.6	10.8	21	Aberjona River	45.9
SW-15	New Boston Street Drainway	511	22.26	22	Aberjona River	33.2
SW-16	Atlantic Avenue Drainway	928	167.7	23	Aberjona River	103.4
SW-17	Aberjona River	58.6	1.94	24	Aberjona River	47.7
Core-1	Hall's Brook	9.9[4]	.23[3]	25	Aberjona River	132.2

NOTES:
[1]   Detection limits ranged from 1,800 mg/kg to 8,900 mg/kg.
[2]   Average concentration from 3 samples collected.
       Golder Associates Inc., PDI-Task S-1, Hazardous Substances in Wetlands and Surface-Water Sediments.
[3]   0.5-0.9 ft depth
[4]   0.2-0.5 ft depth

	Cr (Total)	Cr (dissolved)	% Dissolved	Cr(VI)	Cr(III)	pH	TOTAL Fe mg/L
TABLE 3-23 CHROMIUM GROUND-WATER SPECIATION DATA (MARCH 1990) INDUSTRI-PLEX SITE, WOBURN, MASSACHUSETTS							
OW-12	39	36	92	<10	>29	7.2	13.9
OW-16	160	138	86	<10	>150	7.8	6.7
OW-17	38	27	71	<10	>28	7.0	16
OW-22	153	4	3	<10	>143	6.3	50.3
OW-28	326	<3	1	--	?	6.6	22.6

Note: Cr(VI) analyzed on unfiltered, unacidified samples.

	As	Cu	Cr	Pb	Hg	Zn
NUMBER OF CASES	819	1,023	1,002	625	657	1,041
MINIMUM	1	0.20	0.30	4.9	0.06	1.0
MAXIMUM	31,000	23,000	81,000	54,000	22,000	130,000
MEAN	67	74	52	610	1.1	180
VARIANCE	33	50	88	17	12	33
STANDARD DEVIATION	6.7	7.2	8.3	5.4	4.8	6.5
STANDARD ERROR	1.1	1.1	1.1	1.1	1.1	1.1
SKEWNESS	1.1	1.2	2.0	0.88	6.6	1.4
KURTOSIS	1.7	0.57	1.1	0.71	1,500	0.82

TABLE 3-24 SUMMARY STATISTICS FOR LOG TRANSFORMED PHASE II RI SOILS DATABASE,* INDUSTRI-PLEX SITE, WOBURN, MASSACHUSETTS

*Roux Associates, Inc., 1984

TABLE 3-25 COMPARISON BETWEEN GEOMETRIC MEAN METAL CONCENTRATIONS IN INDUSTRI-PLEX PHASE II SOILS DATA WITH RANGE OF BACKGROUND CONCENTRATIONS REPORTED FOR SOILS OVERLYING GNEISS*

	INDUSTRI-PLEX SOILS	RANGE IN AVERAGE SOILS OVERLYING GNEISS	RATIO OF INDUSTRI-PLEX:AVERAGE
As	70	0.7-15	5
Cu	74	7-70	1
Cr	52	4-25	2
Hg	1.1	0.01-0.14	8
Pb	602	10-50	12
Zn	181	30-125	1.5

*Kabata-Pendias and Pendias, 1984

TABLE 3-26 CORRELATION COEFFICIENTS AND FREQUENCY TABLE FOR PHASE II RI SOILS DATABASE.[1] CRITICAL CORRELATION FOR n=500 IS 0.12 AT THE 1% LEVEL[2]

PEARSON CORRELATION MATRIX

	As	Cu	Cr	Pb	Hg	Zn
As	1.00					
Cu	0.71	1.00				
Cr	-0.02	0.16	1.00			
Pb	0.72	0.65	-0.08	1.00		
Hg	0.48	0.30	0.04	0.37	1.00	
Zn	0.54	0.80	0.32	0.49	0.11	1.00

FREQUENCY TABLE

	As	Cu	Cr	Pb	Hg	Zn
As	819					
Cu	814	1023				
Cr	782	983	1002			
Pb	596	619	594	625		
Hg	609	648	625	621	657	
Zn	819	1022	1002	625	625	1041

[1]Roux Associates, Inc., 1984
[2]Snedecor, 1956

TABLE 3-27   RESULTS OF LOGNORMAL TRANSFORMATION AND COMPUTATION OF t-STATISTIC FOR As, Cr AND Pb INDUSTRI-PLEX SITE WOBURN, MASSACHUSETTS

	HIDES			NO HIDES		
	As	Cr	Pb	As	Cr	Pb
No. of cases	111	131	1.2	1358	1527	1127
Mean [a]($\log_n$)	3.15	6.54	4.71	3.93	3.73	5.74
σ[a]($\log_n$)	1.47	1.66	1.54	1.96	1.86	2.02

BARTLETT'S TEST			RESULT	
	b	$b_{critical}$		
As	1.06	0.98	$\sigma^2_{hide\ soil}$	$= \sigma^2_{no\ hide\ soil}$
Cr	0.98	0.88	$\sigma^2_{hide\ soil}$	$= \sigma^2_{no\ hide\ soil}$
Pb	0.99	0.98	$\sigma^2_{hide\ soil}$	$= \sigma^2_{no\ hide\ soil}$

t-STATISTIC*		RESULT	
As	4.1	hide soil	$\neq$ no hide soil
Cr	16.8	hide soil	$\neq$ no hide soil
Pb	4.8	hide soil	$\neq$ no hide soil

*The critical values of t for > 120 degrees of freedom at the 5% level assuming a two-tailed test is 1.96 (Davis, 1986)

[a] original units prior to transformation were mg/kg.

PEARSON CORRELATION MATRIX

	AL	AS	BA	CA	CU
AL	1.000				
AS	-0.139	1.000			
BA	-0.250	0.442	1.000		
CA	-0.176	0.051	-0.060	1.000	
CU	0.150	-0.259	0.008	-0.153	1.000
FE	-0.219	0.618	0.465	0.466	-0.215
MG	-0.176	0.530	0.396	0.581	-0.328
MN	-0.352	-0.005	0.121	0.405	-0.054
NI	0.001	0.640	0.418	-0.290	-0.054
K	-0.117	0.615	0.276	0.314	-0.150
NA	-0.337	0.307	0.044	0.355	-0.134
V	-0.146	0.767	0.536	-0.032	-0.149
ZN	-0.012	-0.109	0.172	-0.013	0.597
ALK	-0.083	0.718	0.360	0.436	-0.415
EH	0.190	-0.518	0.097	-0.431	0.528
PH	-0.082	0.614	-0.043	0.237	-0.589
SO4	-0.464	0.160	0.001	0.389	0.038
PO4	-0.317	0.624	0.446	0.464	-0.209
TOC	-0.320	0.025	0.099	0.839	0.020
TSS	-0.084	0.292	0.089	0.005	-0.388
COD	0.011	0.758	0.417	0.319	-0.091

	FE	MG	MN	NI	K
FE	1.000				
MG	0.475	1.000			
MN	0.411	0.044	1.000		
NI	0.083	0.508	-0.356	1.000	
K	0.353	0.747	0.025	0.496	1.000
NA	-0.010	0.564	-0.035	0.215	0.576
V	0.276	0.717	-0.240	0.893	0.656
ZN	0.125	-0.367	0.242	-0.173	-0.083
ALK	0.550	0.900	0.082	0.596	0.765

TABLE 3-28. CORRELATION MATRIX FOR TRANSFORMED,
STANDARDIZED GROUND-WATER DATA COLLECTED
BETWEEN 3/15/90 AND 4/25/90
INDUSTRI-PLEX SITE, WOBURN, MASSACHUSETTS

PEARSON CORRELATION MATRIX   Page 2 of 2

(continued)	FE	MG	MN	NI	K
EH	-0.409	-0.573	-0.124	-0.158	-0.409
PH	0.152	0.621	-0.195	0.485	0.484
SO4	0.113	0.256	0.385	-0.015	0.148
PO4	0.443	0.905	0.037	0.592	0.760
TOC	0.495	0.398	0.448	-0.365	0.294
TSS	0.099	0.344	0.026	0.295	0.243
COD	0.476	0.781	0.013	0.709	0.739

	NA	V	ZN	ALK	EH
NA	1.000				
V	0.454	1.000			
ZN	-0.234	-0.265	1.000		
ALK	0.396	0.758	-0.377	1.000	
EH	-0.425	-0.333	0.602	-0.578	1.000
PH	0.545	0.600	-0.621	0.683	-0.778
SO4	0.414	0.089	0.016	0.198	-0.345
PO4	0.718	0.792	-0.241	0.846	-0.503
TOC	0.341	-0.096	0.301	0.161	-0.282
TSS	0.053	0.323	-0.647	0.477	-0.432
COD	0.420	0.789	-0.047	0.805	-0.415

	PH	SO4	PO4	TOC	TSS
PH	1.000				
SO4	0.359	1.000			
PO4	0.596	0.320	1.000		
TOC	-0.022	0.303	0.335	1.000	
TSS	0.423	-0.172	0.275	-0.243	1.000
COD	0.521	0.144	0.799	0.237	0.159

	COD
COD	1.000

TABLE 3-29 SATURATION INDICES FOR SELECTED MONITORING WELLS, INDUSTRI-PLEX SITE, WOBURN, MASSACHUSETTS						
	OW-21	OW-16	OW-12	OW-17	OW-19A	OW-7
Calcite($CaCO_3$)	-2.0	0.8	0.7	0.5	-2.0	-2.1
Gypsum ($CaSO_4.2H_2O$)	-2.0	-16	0.2	-0.4	-1.7	-1.8
Lepidocrocite ($\gamma FeO.OH$)	-0.7	2.3	0.5	-0.6	1.1	2.1
Goethite (FeO.OH)	-0.5	2.5	0.8	-0.3	1.4	2.4
Siderite ($FeCO_3$)	-2.7	1.5	0.5	-0.1	-1.6	-2.7
Vivianite [$Fe_3(PO_4)_2$]	-8.4	1.9	0.1	-1.5	-4.0	-6.1
Barite ($BaSO_4$)	-0.4	-13	1.1	0.6	0.1	-0.2
$Ba_3(AsO_4)_2$	-0.6	13	-0.7	-1.6	3.6	-14.7
$Cr(OH)_3(a)$	-13	2.2	1.4	1.1	-13	-12.4
$Cr_{0.25} Fe_{0.75} (OH)_3$	-10	13	6.9	3.6	-5.7	-2.0
Charge imbalance	+20%	-80%	-18%	+7%	-12%	0%
Ionic strength	0.005	0.1	0.06	0.06	0.005	0.006

Negative charge imbalance = anion excess.
Positive charge imbalance = cation excess.

TABLE 4.1

DESCRIPTIVE STATISTICS FOR TOTAL METALS
MEASURED IN SURFACE WATER

Groundwater/Surface Water Investigation Plan
Industri-Plex Superfund Site
Woburn, MA

METALS (Total)	DETECTION LIMIT		FREQUENCY OF DETECTION	RANGE FOR REFERENCE AREAS		MEAN FOR REFERENCE AREAS	RANGE FOR SITE AREAS		LOCATION OF MAXIMUM VALUE	MEAN FOR SITE AREAS	SITE/ REFERENCE RATIO	RANKING METHOD	
	I	C		MIN	MAX		MIN	MAX				BACK-GROUND	TOXICITY SCREEN
Aluminum	15	200	6 / 15	ND	198.0	57.0	ND	646	SW-7	25.2	0.4	16	
Antimony	19	60	2 / 15	ND	ND	9.5	20.1	25.7	SW-15	11.0	1.2	11	1
Arsenic	2	10	10 / 15	ND	1.0	1.0	ND	40.6	SW-2	7.7	7.8	1	2
Barium	1	200	14 / 15	18.5	31.0	22.3	ND	67.7	SW-6	24.7	1.1	12	6
Calcium	14	5000	15 / 15	15,100.0	29,900.0	23405.7	26,400.0	55000	SW-6	32931.2	1.4	10	
Chromium	3	10	10 / 15	ND	3.6	2.0	ND	62.6	SW-7	5.9	3.0	4	9
Cobalt	3	50	1 / 15	ND	ND	1.5	ND	5.1	SW-15	1.7	1.1	13	
Copper	3	25	7 / 15	ND	5.7	2.3	ND	13.5	SW-9	3.8	1.6	9	8
Iron	3	100	15 / 15	924.0	1,160.0	1037.9	446.0	4880	SW-6	1928.3	1.9	5	
Lead	2	5	13 / 15	2.2	4.3	3.4	ND	8.6	SW-10	3.3	1.0	15	4
Magnesium	23	5000	15 / 15	2,940.0	4,710.0	3734.1	4,780.0	11500	SW-6	6491.1	1.7	8	
Manganese	1	15	15 / 15	83.3	144.0	104.6	197.0	1840	SW-15	597.5	5.7	2	3
Potassium	428	5000	14 / 15	ND	3,200.0	1198.7	2,460.0	11800	SW-6	4834.6	4.0	3	
Silver	2	10	1 / 15	ND	ND	1.0	ND	2	SW-10	1.1	1.1	14	7
Sodium	18	5000	15 / 15	10,100.0	60,200.0	26220.9	9,820.0	146000	SW-7	43160.0	1.6	8	
Zinc	6	20	12 / 15	14.3	20.3	17.0	ND	276	SW-9	28.2	1.7	7	5

1

All values are ppb. Duplicate samples were averaged together. Reference areas are upstream of the site (SW-1, 4, and 8).
Site areas are all samples exclusive of the reference area. Data is presented in tabular form in Appendix C.

2

I = Instrument; C = Contract Required. Samples below the Instrument Detection Limit were not included in the database.

3

Beryllium, cadmium, mercury, nickel, selenium, thallium, vanadium, and tin were not dectected above the instrument
detection limit. SW-3 and SW-16 were dry at the low flow sampling period.

4

The sample mean is the geometric mean, using one-half of the instrument detection limit for trace and/or non-detected values.
Note that, because non-detects are considered one-half of the detection limit when calculating means, some metals may have
means that are lower than the minimum value for that dataset.

5

The metals have been ranked using two different methods. The BACKGROUND method divides the site area mean by the reference area
mean and ranks the ratios in descending order. A ratio greater than one indicates that the mean metal concentration for the site
areas exceed the mean metal concentration for the reference areas. Note that ratios which had non-detects (ND) for the reference
area may be biased. The TOXICITY method uses the "concentration-toxicity screening method" developed in RAGS. This method divides
the maximum detected concentration by a toxicity value (RfD) and rank orders the quotient in decending order. It is generally intended
to assist in the indicator selection process, but does not take into account frequency of detection or exposure.

6

RfD used for chromium was for Cr(III). RfDs for copper and lead were calculated from the Federal MCL.

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TABLE 4.2

DESCRIPTIVE STATISTICS FOR DISSOLVED METALS
MEASURED IN SURFACE WATER

Groundwater/Surface Water Investigation Plan
Industri-Plex Superfund Site
Woburn, MA

METALS (Dissolved) [1]	DETECTION LIMIT [2]		FREQUENCY OF DETECTION [3]	RANGE FOR REFERENCE AREAS		MEAN FOR REFERENCE AREAS [4]	RANGE FOR SITE AREAS		LOCATION OF MAXIMUM VALUE	MEAN FOR SITE AREAS [4]	SITE/ REFERENCE RATIO	SITE RANKING [5]
	(I)	(C)		MIN	MAX		MIN	MAX				
Aluminum	15	200	8 / 15	ND	20.4	10.5	ND	191	SW-12	34.4	3.3	4
Antimony	19	60	3 / 15	ND	ND	13.0	ND	24.8	SW-15	11.0	0.8	13
Arsenic	2	10	12 / 15	ND	ND	1.0	ND	24.5	SW-2	8.1	8.1	3
Barium	1	200	15 / 15	14.6	27.3	19.0	23.6	106	SW-6	54.9	2.9	5
Calcium	14	5000	15 / 15	16,550.0	31,800.0	25170.3	27200	56300	SW-6	33907.5	1.3	9
Copper	3	25	3 / 15	ND	ND	1.5	ND	4	SW-14	1.9	1.3	10
Iron	3	100	14 / 15	339.5	512.0	412.2	ND	1670	SW-2	418.1	1.0	12
Magnesium	23	5000	15 / 15	3,170.0	4,930.0	3995.0	4850	11800	SW-6	6788.9	1.7	7
Manganese	1	15	15 / 15	47.3	97.6	67.1	191	2860	SW-6	643.3	9.6	2
Potassium	428	5000	15 / 15	1,990.0	3,570.0	2698.2	2460	12500	SW-6	5152.7	1.9	6
Silver	2	10	2 / 15	ND	ND	1.0	ND	2.4	SW-6	1.1	1.1	11
Sodium	18	5000	15 / 15	10,600.0	66,100.0	28928.0	10800	149000	SW-7	45742.6	1.6	8
Zinc	6	20	12 / 15	ND	8.4	4.2	ND	276	SW-9	47.3	11.2	1

1
All values are ppb. Duplicate samples were averaged together. SW-3 and -16 were dry at the time of sampling. Reference areas
are considered upstream of the site (SW-1, -4, -6). Site areas are all samples exclusive of the reference area. Database includes
qualitative data and is presented in tabular form in Appendix C.
2
I = Instrument; C = Contract Required. Samples below the Instrument Detection Limit were not included in the database.
3
Beryllium, cadmium, chromium, cobalt, lead, mercury, nickel, selenium, thallium, vanadium, and tin were not
detected above the instrument detection limit. SW-3 and SW-16 were dry at the low flow sampling period.
4
The sample mean is the geometric mean, using one-half of the instrument detection limit for trace and/or non-detected values.
Note that, because non-detects are considered one-half of the detection limit when calculating means, some metals may have
means that are higher than the minimum value for that dataset.
5
The metals have been ranked, based on the site area/reference area ratio, to gain perspective on the relative amounts of
dissolved metal present in the water. A ratio greater than one indicates that the mean metal concentration for the site areas
exceeds the mean metal concentration for the reference areas. Note that ratios which had non-detects for the reference
area may be biased, e.g. the reference area mean for arsenic is wholly based on using one-half of the detection limit. There-
fore, arsenic may be ranked lower than that cited here.

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TABLE 4.3

DESCRIPTIVE STATISTICS FOR VOLATILE ORGANIC COMPOUNDS
MEASURED IN SURFACE WATER

Groundwater/Surface Water Investigation Plan
Industri-Plex Superfund Site
Woburn, MA

COMPOUND NAME [1]	DETECTION LIMIT [2]		FREQUENCY OF DETECTION	RANGE		LOCATION OF MAXIMUM VALUE	MEAN (ppb) [N = 15] [3]
	(I)	(C)		MIN	MAX		
Acetone	2	10	1 / 15	ND	2	SW-8	1.0
Chlorobenzene	1	5	2 / 15	ND	2	SW-6	0.5
Dichloroethane, 1,1-	1	5	1 / 15	ND	3	SW-9	0.5
Dichloroethene, 1,2-	1	5	4 / 15	ND	11	SW-9	0.8
Methylene chloride	2	5	8 / 15	ND	8	SW-11	2.7
Toluene	1	5	2 / 15	ND	2	SW-7	0.6
Trichloroethane, 1,1,1-	1	5	2 / 15	ND	9	SW-13	0.7
Trichloroethene	1	5	4 / 15	ND	11	SW-9	0.9
Xylenes (total)	1	5	1 / 15	ND	1	SW-11	0.5

1

All values are ppb. Duplicate samples were averaged together. Stations SW-3 and SW-16 were dry at the time of sampling.
SW-1, -2, -5, -12, and -17 had no detectable levels of volatile organic compounds. The majority of this database consists of
qualitative data, which is presented in tabular form in Appendix C.

2

I = Instrument; C = Contract Required. Values below the Instrument Detection Limit were not included in the database.

3

The sample mean is the geometric mean, using one-half of the instrument detection limit for trace and/or non-detected values.
Note that, using this procedure, the mean value may be less than the minimum value cited.

TABLE 4.4

DESCRIPTIVE STATISTICS FOR SEMIVOLATILE ORGANIC COMPOUNDS
MEASURED IN SURFACE WATER

Groundwater/Surface Water Investigation Plan
Industri-Plex Superfund Site
Woburn, MA

1 COMPOUND NAME (Unfiltered Samples)	2 DETECTION LIMIT		FREQUENCY OF DETECTION	RANGE		LOCATION OF MAXIMUM VALUE	3 MEAN (ppb) [N = 15]
	(I)	(C)		MIN	MAX		
Butylbenzylphthalate	5	10	1 / 15	ND	2	SW-11	2.5
Di-n-butylphthalate	3	10	1 / 15	ND	1	SW-14	1.5
bis (2-Ethylhexyl) phthalate	4	10	5 / 15	ND	12	SW-11	2.4
Diethylphthalate	4	10	3 / 15	ND	3	(see 4)	2.2
N-Nitrosodiphenylamine	5	10	1 / 15	ND	1	SW-11	2.4

1

All values are ppb. Duplicate samples were averaged together. Stations SW-1, -2, -4, -5, -6, -8, -9, -12 and -17 had
no detectable levels of semivolatile compounds. The majority of this database consists of qualitative data, which is
presented in tabular form in Appendix .

2

I = Instrument; C = Contract Required. Values below the instrument Detection Limit were not included in the database.

3

The sample mean is the geometric mean, using one-half of the instrument detection limit for trace and/or non-detected values.

4

SW-11, -13, and 14 all had concentrations of 3 ppb diethylphthalate.

Table 4.5

DESCRIPTIVE STATISTICS FOR SELECTED WATER QUALITY PARAMETERS
OF UNFILTERED SURFACE WATER SAMPLES

Industri-Plex Superfund Site
Woburn, MA

1 CHEMICAL PARAMETER	2 DETECTION LIMIT (I)	FREQUENCY OF DETECTION	3 RANGE MIN	MAX	LOCATION OF MAXIMUM VALUE	4 MEAN [N = 15]
Alkalinity, Bicarb. as CaCO3	5.0	15 / 15	21.8	300.0	SW-6	80.8
Chemical Oxygen Demand	20.0	15 / 15	20.0	90.7	SW-2	29.5
Chloride	6.0	15 / 15	11.7	177.0	SW-7	60.1
Hardness		15 / 15	50.4	185.0	SW-6	101.6
Total Organic Carbon (%)	0.5	15 / 15	5.5	15.3	SW-6	8.5
Orthophosphate as P	0.010	1 / 15	0.1	0.1	SW-10	0.01
Phosphorous, total	0.05	13 / 15	0.1	0.2	SW-6	0.1
Sulfate	5.0	15 / 15	19.5	152.0	SW-7	48.2
Suspended Solids (total)	5.0	7 / 15	6.0	30.0	SW-8	4.9
pH		11 / 15	5.6	7.9	SW-8	1.0

1

All units in mg/kg dry weight, except for pH and total organic carbon (% dry weight).
Database includes qualitative data. Duplicate samples were averaged together.
Hardcopy of complete database presented in Appendix C.

2

The detection limit for the majority of analyses (I=instrument; CR=contract required).
The detection limit may vary for individual samples.

3

The location for the lowest pH value was SW-12 (pH = 5.6).

4

The sample mean is the geometric mean, using one-half of the instrument detection limit
for trace and/or non-detected values. Note that, using this procedure, the mean value
may be less than the minimum value cited for the sampling round.

Table 4.6

DESCRIPTIVE STATISTICS FOR TOTAL METALS (ppm) MEASURED IN SEDIMENT

Groundwater/Surface Water Investigation Plan
Industri-Plex Superfund Site
Woburn, MA

1 METAL	2 DETECTION LIMITS		3 FREQUENCY OF DETECTION	3 RANGE FOR REFERENCE AREAS		4,7 MEAN FOR REFERENCE AREAS	RANGE FOR SITE AREAS		LOCATION OF MAXIMUM VALUE	6,7 MEAN FOR SITE AREAS	SITE/ REFERENCE RATIO	6 RANKING METHOD	
	(I)	(CR)		MIN	MAX		MIN	MAX				BACK-GROUND	TOXICITY SCREEN
Aluminum	15	200	20 / 20	3430	19900	6847.2	922	15800	SW-9	4932.5	0.72	22	
Antimony	17	60	8 / 20	ND	11.7	7.2	ND	375	SW-7	13.9	1.92	14	3
Arsenic	2	10	69 / 70	ND	69.6	6.1	1.6	9630	SW-9	96.7	15.78	1	2
Barium	1	200	20 / 20	4	49.5	13.9	7.8	462	SW-7	56.2	4.04	6	9
Beryllium	1	5	10 / 20	ND	0.48	0.4	ND	3.7	SW-9	0.7	1.92	15	17
Cadmium	3	5	11 / 20	ND	1.2	1.3	ND	61.5	SW-9	4.0	3.06	9	6
Calcium	14	5000	20 / 20	595	2220	1108.2	655	14900	SW-9	2180.0	1.97	13	
Chromium	3	10	70 / 70	6.2	61.7	14.1	7	10700	SW1/002	146.2	10.38	4	13
Cobalt	3	50	20 / 20	1.3	9.9	3.0	1.6	41.9	SW-11	7.1	2.39	12	
Copper	3	25	20 / 20	0.59	44.3	10.9	12.2	1160	SW-9	91.7	8.42	5	8
Iron	3	100	20 / 20	1900	31400	6869.7	6640	112000	SW-9	26456.6	3.85	7	
Lead	2	5	66 / 70	ND	487	11.2	ND	4700	SW1/016	144.7	12.94	2	1
Magnesium	23	5000	20 / 20	286	5710	1576.3	513	4860	SW-9	1676.1	1.06	19	
Manganese	1	15	20 / 20	22.4	174	66.4	48.4	1150	SW-9	239.7	3.61	8	12
Mercury	0.2	0.2	9 / 20	ND	0.2	0.11	ND	9.5	SW-7	0.29	2.62	10	7
Nickel	24	40	8 / 20	ND	27.7	11.4	ND	44.6	SW-11	9.5	0.84	20	15
Potassium	428	5000	20 / 20	332	2160	736.7	287	2040	SW-9	600.6	0.81	21	
Selenium	2	5	9 / 20	ND	1	0.9	ND	41.4	SW-16	2.3	2.55	11	11
Silver	2	10	7 / 20	ND	1.3	1.0	ND	13.6	SW-7	1.5	1.49	18	14
Sodium	18	5000	16 / 20	62.2	597	225.6	ND	12700	SW-9	99.9	0.44	24	
Thallium	4	10	3 / 20	ND	0.64	1.4	ND	38.4	SW-7	2.5	1.77	16	4
Tin	17	—	17 / 18	12.5	1010	43.7	ND	1230	SW-9	27.2	0.62	23	16
Vanadium	3	50	20 / 20	3.6	32.5	11.4	4.9	159	SW-16	15.3	1.60	17	10
Zinc	6	20	20 / 20	6.3	71.3	26.2	46.7	7940	SW-9	331.7	12.66	3	6

1

Qualitative and quantitative data taken from analyses performed to fulfill requirements of the GSIP and the PDI. Duplicate samples were averaged together. Hardcopy of completed database presented in Appendix C.

2

The detection limit for the majority of analyses (I-instrument; CR-contract required). The detection limit may vary for individual samples. In general, the GSIP had consistent detection limits but a low incidence of quantitative data, while the PDI had varying detection limits but a higher incidence of quantitative data.

3

Sample size for most metals is N = 20, with the exception of tin (N = 18), and arsenic, chromium, and lead (N = 70, as a result of inclusion of PDI data).

4

Reference areas are defined as samples taken in locations that have a very low probability of past contamination, based on conclusions reached in the RI/FS. The mean concentrations (geometric) for the reference areas were calculated using one-half of the detection limit for non-detects. Sampling locations chosen for calculating the mean sediment reference concentrations were located in Upper South Pond (north of spillway) and east of Commerce Way (based on conclusions of RI/FS). These locations include SW-1, -3, -4, -6, (GSIP) and SW1/040, 042 – 047, 049 – 052, 055 – 057, 059 (PDI, Figure 8).

5

Site areas are defined as samples taken in locations having some potential for past contamination (RI/FS). The mean concentrations (geometric) for the Site areas were calculated using one-half of the detection limit for non-detects. Sampling locations chosen include SW-1, 2, 5-7, 9-17, and CORE (GSIP); SW1/001-007, 012-039, 041, and 048 (PDI, Figure 8). PDI sediment SW1/003 – 007, 014 – 026, and 050 – 052, are the mean of three samples (transect). Database only includes surficial samples (0-6").

6

The metals have been ranked using two different methods. The BACKGROUND method divides the site area mean by the reference area mean and ranks the ratios in decending order. A ratio greater than one indicates that the mean metal concentration for the site areas exceed the mean metal concentration for the reference areas. Note that ratios which had non-detects (ND) for the reference area may be biased. The TOXICITY SCREEN method uses the "concentration-toxicity screening method" developed in RAGS. This method divides the maximum detected concentration by a toxicity value (RfD) and rank orders the quotient in decending order. It is intended to assist in the Hazard ID process, but ignores exposure and/or frequency of detection.

7

Because non-detects were considered one-half of the detection limit when calculating means, some metals may have means that are higher than the maximum value for that dataset.

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TABLE 4.7

DESCRIPTIVE STATISTICS FOR VOLATILE ORGANIC COMPOUNDS
MEASURED IN SEDIMENT

Groundwater/Surface Water Investigation Plan
Industri-Plex Superfund Site
Woburn, MA

1 COMPOUND NAME	2 DETECTION LIMIT		FREQUENCY OF DETECTION	RANGE		LOCATION OF MAXIMUM VALUE	3 MEAN [N = 19]
	(I)	(C)		MIN	MAX		
Acetone	2	10	7 / 19	ND	470	SW-11	6.1
Benzene	1	5	3 / 19	ND	2,100	SW-9	1.4
2-Butanone	1	10	2 / 19	ND	71	SW-13	0.8
Chlorobenzene	1	5	1 / 19	ND	440	SW-6	0.7
1,2-Dichloroethane	1	5	1 / 19	ND	28	SW-9	0.6
1,2-Dichloroethene	1	5	1 / 19	ND	2	SW-7	0.5
Ethylbenzene	1	5	2 / 19	ND	40	SW-9	0.7
2-Hexanone	2	10	1 / 19	ND	9	SW-5	1.1
Methylene chloride	2	5	12 / 19	ND	39	SW-9	3.0
4-Methyl-2-pentanone	2	10	1 / 19	ND	2	SW-5	1.0
Tetrachloroethene	1	5	3 / 19	ND	11	SW-15	0.7
Toluene	1	5	2 / 19	ND	250	SW-6	0.8
Trichloroethene	1	5	3 / 19	ND	3	SW-7	0.6

1

All values are ppb. Duplicate samples were averaged together. Stations SW-3, 4, 8 and 9 had no detectable levels
of volatile compounds. The majority of this database consists of qualitative data, which is presented in tabular
form in Appendix C. This database also includes data from the PDI.

2

I = Instrument; C = Contract Required. Values below the Instrument Detection Limit were not included in the database.

3

The sample mean is the geometric mean, using one-half of the instrument detection limit for trace and/or non-detected values.
Note that, using this procedure, the mean value may be less than the minimum value cited for the sampling round.

TABLE 4.8

DESCRIPTIVE STATISTICS FOR SEMIVOLATILE ORGANIC COMPOUNDS
MEASURED IN SEDIMENT

Groundwater/Surface Water Investigation Plan
Industri-Plex Superfund Site
Woburn, MA

1 COMPOUND NAME	2 DETECTION LIMIT		FREQUENCY OF DETECTION	RANGE OF VALUES		LOCATION OF MAXIMUM VALUE	3 MEAN (ppb) [N = 19]
	(I)	(C)		MIN	MAX		
Benzoic acid	25	50	1 / 19	ND	1,300	SW-17	12
bis (2-Ethylhexyl) phthalate	4	10	13 / 19	ND	90,000	SW-07	160
Butylbenzylphthalate	5	10	1 / 19	ND	1,600	SW-14	3
Dibenzofuran	4	10	2 / 19	ND	540	SW-12	3
3,3'-Dichlorobenzidine	5	20	1 / 19	ND	3,300	SW-14	3
Diethylphthalate	4	10	2 / 19	ND	2,100	SW-11	4
2,4-Dinitrotoluene	10	10	1 / 19	ND	2,900	SW-12	8
N-Nitrosodiphenylamine	5	10	1 / 19	ND	100	SW-15	3
Pentachlorophenol			1 / 19	ND	85	SW1/011	1
PAH COMPOUNDS							
Acenaphthylene	3	10	1 / 19	ND	180	SW-15	2
Anthracene	3	10	6 / 19	ND	2,900	SW-12	11
Benzo (a) anthracene	3	10	10 / 19	ND	15,000	SW-16	41
Benzo (a) pyrene	3	10	10 / 19	ND	12,000	SW-16	38
Benzo (b) fluoranthene	3	10	11 / 19	ND	27,000	SW-16	59
Benzo (g,h,i)perylene	3	10	7 / 19	ND	5,700	SW-16	15
Benzo (k) fluoranthene	3	10	10 / 19	ND	27,000	SW-16	60
Chrysene	3	10	10 / 19	ND	13,000	SW-12	45
Dibenzo (a,h) anthracene	3	10	3 / 19	ND	3,100	SW-16	4
Fluoranthene	3	10	12 / 19	ND	24,000	SW-12	107
Fluorene	4	10	1 / 19	ND	240	SW-15	2
Indeno (1,2,3-cd) pyrene	4	10	7 / 19	ND	5,800	SW-16	18
Naphthalene	3	10	1 / 19	ND	60	SW1/011	1
Phenanthrene	3	10	11 / 19	ND	17,000	SW-12	66
Pyrene	3	10	12 / 19	ND	22,000	SW-12	100

1

All values are ppb. Duplicate samples were averaged together. Stations SW-3, 4, 8 and 9 had no detectable levels
of semivolatile compounds. The majority of this database consists of qualitative data, which is presented in tabular
form in Appendix C. This database includes information from the PDI.

2

I = Instrument; C = Contract Required. Values below the Instrument Detection Limit were not included in the database.

4

The sample mean is the geometric mean, using one-half of the Instrument detection limit for trace and/or non-detected values.

TABLE 4.9

DESCRIPTIVE STATISTICS FOR SELECTED WATER CHEMISTRY
PARAMETERS IN SEDIMENT

Groundwater/Surface Water Investigation Plan
Industri-Plex Superfund Site
Woburn, MA

ANALYSIS PARAMETER [1]	DETECTION LIMIT (I) [2]	FREQUENCY OF DETECTION	RANGE OF VALUES [3]		LOCATION OF MAXIMUM VALUE	MEAN [N = 17] [4]
			MIN	MAX		
Total Organic Carbon	0.010	17 / 17	0.2	23.0	SW-16	1.2
Alkalinity, as CaCO3	NA	17 / 17	1.2	39.1	SW-9	8.4
Trivalent Chromium	NA	17 / 17	7.0	1,090.0	SW-9	79.1
Hexavalent Chromium	NA	17 / 17	0.6	7.8	SW-9	1.7
pH	NA	17 / 17	5.8	7.9	SW-6	6.9

1
All units in mg/kg dry weight, except for pH and total organic carbon (% dry weight).
Database includes qualitative data. Duplicate samples were averaged together.
Hardcopy of complete database presented in Appendix C.

2
The detection limit for the majority of analyses (I=instrument; CR=contract required).
The detection limit may vary for individual samples.

3
The location for the lowest pH value was SW-3 (pH = 5.8).

4
The sample mean is the geometric mean, using one-half of the instrument detection limit for trace and/or non-detected value
Note that, using this procedure, the mean value may be less than the minimum value cited for the sampling round.

TABLE 4.10
DESCRIPTIVE STATISTICS FOR TOTAL METALS
MEASURED IN GROUNDWATER
Groundwater/Surface Water Investigation Plan
Industri-Plex Superfund Site

METALS (Total)	DETECTION LIMIT [2]		FREQUENCY OF DETECTION n=65 [3]	RANGE FOR REFERENCE AREAS [4]		MEAN FOR REFERENCE AREAS	RANGE FOR SITE AREAS		LOCATION OF MAXIMUM VALUE	MEAN FOR SITE AREAS [4]	REFERENCE SITE RATIO	SITE RANKING [5]
	(I)	(C)		MIN	MAX		MIN	MAX				
Aluminum	27	200	63 / 65	44.3	7150	503.6	ND	224000	OW-28	848.9	1.7	9
Antimony	37	60	27 / 65	ND	17.3	18.3	ND	143	OW-40	23.4	1.3	13
Arsenic	2	10	46 / 65	ND	5.05	1.4	ND	2350	OW-16	16.7	12.0	1
Barium	2	200	52 / 65	ND	23.9	6.9	ND	505	OW-17	22.8	3.3	3
Beryllium	1	5	8 / 65	ND	1	0.6	ND	8.8	OW-28	0.6	1.0	21
Cadmium	5	5	11 / 65	ND	ND	2.5	ND	27.4	OW-18	3.2	1.3	14
Calcium	20	5000	65 / 65	24200	162000	51229.8	3810	517000	OW-12	56605.0	1.1	19
Chromium	3	10	51 / 65	ND	19	5.4	ND	428	OW-09	11.8	2.2	7
Cobalt	7	50	26 / 65	ND	47.6	5.9	ND	157	OW-28	7.3	1.2	15
Copper	6	25	33 / 65	ND	40.1	8.1	ND	1350	OW-10	9.1	1.1	18
Iron	3	100	65 / 65	716	30700	2627.2	322	226000	OW-28	5887.1	2.2	6
Lead	2	5	37 / 65	ND	3.4	1.6	ND	299	OW-14	3.9	2.4	4
Magnesium	37	5000	65 / 65	4390	25300	7787.6	1110	224000	OW-16	11711.5	1.5	10
Manganese	1	15	65 / 65	92.5	2810	899.3	16.3	26700	OW-23	536.1	0.6	22
Mercury	0.2	0.2	6 / 65	ND	ND	0.1	ND	1.6	OW-40	0.1	1.1	17
Nickel	12	40	28 / 65	ND	71.9	9.9	ND	322	OW-09	13.2	1.3	12
Potassium	900	5000	59 / 65	ND	7220	2549.2	ND	74800	OW-16	4984.4	2.0	8
Selenium	2	5	10 / 65	ND	2	1.2	ND	78	OW-40	1.4	1.2	16
Silver	3	10	3 / 65	ND	571	4.9	ND	21.2	OW-22	1.6	0.3	23
Sodium	38	5000	65 / 65	8790	105000	21458.8	74.1	757000	OW-17	30528.7	1.4	11
Thallium	2	10	2 / 65	ND	ND	1.0	ND	2.7	OW-18	1.0	1.0	20
Vanadium	6	50	33 / 65	ND	6.6	3.5	ND	370	OW-28	8.3	2.4	5
Zinc	8	20	53 / 65	ND	27	16.5	ND	9470	OW-10	57.6	3.5	2

TBL4-10x.WR1

1

The values cited in this table were derived from the combined PDI and GSIP datasets. All values are in parts per billion.
Duplicate samples were averaged together. Reference areas are upgradient of the site (OW-1, 1A, 21, and 4). Site areas
are all wells exclusive of the reference area. Data is presented in tabular form in Appendix C.

2

I – Instrument; C – Contract Required. Samples below the Instrument Detection Limit were not included in the database.

3

Tin was not detected above the detection limit.

4

The sample mean is the geometric mean, using one-half of the Instrument detection limit for trace and/or non-detected values.
Note that, because non-detects are considered one-half of the detection limit when calculating means, some metals may have
means that are lower than the minimum value for that dataset.

5

The metals have been ranked, based on the site area/reference area ratio, to gain perspective on the relative amounts of
metals present in the groundwater. A ratio greater than one indicates that the mean metal concentration for the site areas exceeds
the mean metal concentration for the reference areas. Note that ratios which had non-detects for the reference area may be biased.

TABLE 4.11
DESCRIPTIVE STATISTICS FOR DISSOLVED METALS
MEASURED IN GROUNDWATER
Groundwater/Surface Water Investigation Plan
Industri-Plex Superfund Site
Woburn, MA

METALS (Dissolved)	DETECTION LIMIT [2]		FREQUENCY OF DETECTION [3]		RANGE FOR REFERENCE AREAS		MEAN FOR REFERENCE AREAS [4]	RANGE FOR SITE AREAS		LOCATION OF MAXIMUM VALUE	MEAN FOR SITE AREAS [4]	SITE/ REFERENCE RATIO	SITE RANKING [5]
	(I)	(C)			MIN	MAX		MIN	MAX				
Aluminum	27	200	26 /	65	ND	5010	84.0	ND	691	OW-1A	35.3	0.4	22
Antimony	37	60	23 /	65	ND	18.7	18.5	ND	122	OW-40	23.1	1.2	14
Arsenic	2	10	36 /	65	ND	3.4	1.3	ND	2400	OW-16	9.2	7.2	2
Barium	2	200	63 /	65	7.2	22.2	12.6	ND	245	OW-16	36.3	2.9	5
Cadmium	5	5	11 /	65	ND	ND	2.5	ND	26.7	OW-18	3.0	1.2	15
Calcium	20	5000	65 /	65	22800	156000	52445.6	3150	662000	OW-40	52812.0	1.0	19
Chromium	3	10	33 /	65	ND	9.8	2.2	ND	498	OW-12	7.3	3.3	3
Cobalt	7	50	11 /	65	ND	ND	3.5	ND	28	OW-38	4.8	1.4	12
Copper	6	25	15 /	65	ND	11.5	3.9	ND	321	OW-10	4.4	1.1	16
Iron	3	100	52 /	65	ND	151	9.4	ND	24500	OW-42	238.7	25.3	1
Lead	2	5	1 /	65	ND	ND	1.0	ND	16.3	OW-14	1.1	1.0	17
Magnesium	37	5000	65 /	65	4960	24600	7801.3	467	231000	OW-16	9969.2	1.3	13
Manganese	1	15	63 /	65	1.4	1485	146.8	ND	8130	G132	331.4	2.3	6
Nickel	12	40	19 /	65	ND	20	7.6	ND	10400	OW-12	11.5	1.5	8
Potassium	900	5000	59 /	65	2350	6440	3072.2	ND	261000	OW-17	4398.3	1.4	9
Selenium	2	5	11 /	65	ND	ND	1.0	ND	63.4	OW-40	1.4	1.4	10
Silver	8.4	—	1 /	65	ND	ND	4.2	ND	3.1	G124A	4.2	1.0	21
Sodium	38	5000	64 /	65	11600	123000	25980.3	ND	663000	OW-17	35666.6	1.4	11
Thallium	2	—	1 /	65	ND	ND	1.0	ND	2.1	OW-38	1.0	1.0	18
Tin	28	—	2 /	65	ND	ND	14.0	ND	59	OW-16	14.0	1.0	20
Vanadium	6	50	15 /	65	ND	ND	3.0	ND	318	OW-36	4.8	1.6	7
Zinc	8	20	44 /	65	ND	26.75	11.0	ND	8990	OW-18	36.3	3.3	4

TBL4-11a.WR1

1

The values cited in this table were derived from the combined PDI and GSIP datasets. All values are in parts per billion.

Duplicate samples were averaged together. Reference areas are upgradient of the site (OW-1, 1A, 21, and 4). Site areas

are all wells exclusive of the reference area. Data is presented in tabular form in Appendix C.

2

I = Instrument; C = Contract Required. Samples below the Instrument Detection Limit were not included in the database.

3

Beryllium and mercury were not detected above the instrument detection limit.

4

The sample mean is the geometric mean, using one-half of the instrument detection limit for trace and/or non-detected values.

Note that, because non-detects are considered one-half of the detection limit when calculating means, some metals may have

means that are lower than the minimum value for that dataset.

5

The metals have been ranked, based on the site area/reference area ratio, to gain perspective on the relative amounts of

metals present in the groundwater. A ratio greater than one indicates that the mean metal concentration for the site areas exceeds

the mean metal concentration for the reference areas. Note that ratios which had non-detects for the reference area may be biased.

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TABLE 4.12

DESCRIPTIVE STATISTICS FOR VOLATILE ORGANIC COMPOUNDS
MEASURED IN GROUNDWATER

Groundwater/Surface Water Investigation Plan
Industri-Plex Superfund Site
Woburn, MA

COMPOUND NAME [1]	DETECTION LIMIT [2]		FREQUENCY OF DETECTION		RANGE OF VALUES		LOCATION OF MAXIMUM VALUE	MEAN (ppb) [N = 66] [3]
	(I)	(C)			MIN	MAX		
Acetone	2	10	5 /	66	ND	267	OW-39	1.3
Benzene	1	5	13 /	66	ND	48,000	OW-31	2.2
Chlorobenzene	1	5	1 /	66	ND	25	OW-01	0.9
Chloroethane	2	10	2 /	66	ND	4	OW-30B	1.0
Chloroform	1	5	4 /	66	ND	6	OW-22	0.9
Chloromethane	2	10	1 /	66	ND	1	OW-01	1.0
1,1-Dichloroethane	1	5	7 /	66	ND	6	OW-07	1.0
1,2-Dichloroethane	1	5	1 /	66	ND	2	OW-17	0.9
1,1-Dichloroethene	1	5	3 /	66	ND	8	OW-26B	0.9
trans-1,2-Dichloroethylene	1	5	3 /	66	ND	28	OW-20	0.9
Ethylbenzene	1	5	4 /	66	ND	6	OW-09	0.9
Methylene Chloride	2	5	3 /	66	ND	23	OW-27	1.2
Toluene	1	5	19 /	66	ND	32,000	OW-16	1.9
Trichloroethene	1	5	5 /	66	ND	110	OW-26B	1.1
1,1,1-Trichloroethane	1	5	4 /	66	ND	26	OW-26B	1.0
Xylenes (total)	1	5	7 /	66	ND	35	OW-09	1.1

TBL4-12A.WR1

[1]

The values cited in this table were derived from the combined PDI and GSIP datasets. All values are in parts per billion.

Duplicate samples were averaged together. OW-1A,9,10,11,14,15,19A,24A,25A,25B,26A,29, and 33A had no detectable concen-

trations of volatile organic compounds. The majority of this database consists of qualitative data, which is presented

in tabular form in Appendix C.

[2]

I = Instrument; C = Contract Required. Values below the instrument Detection Limit were not included in the database.

[3]

The sample mean is the geometric mean, using one-half of the instrument detection limit for trace and/or non-detected values.

Note that, using this procedure, the mean value may be less than the minimum value cited for the sampling round.

TBL4-13.WR1

TABLE 4.13

DESCRIPTIVE STATISTICS FOR SEMIVOLATILE ORGANIC COMPOUNDS MEASURED IN GROUNDWATER

Groundwater/Surface Water Investigation Plan
Industri-Plex Superfund Site
Woburn, MA

COMPOUND NAME [1]	DETECTION LIMIT [2]		FREQUENCY OF DETECTION	RANGE OF VALUES		LOCATION OF MAXIMUM VALUE	MEAN [N = 38] [3]
	(I)	(C)		MIN	MAX		
Acenaphthene	3	10	1 / 38	ND	3	OW-26A	1.5
Benzoic acid	25	50	2 / 38	ND	2,000	OW-18	14.9
bis (2-Ethylhexyl) phthalate	4	10	5 / 38	ND	64	OW-16	2.4
2-Methylphenol	5	10	1 / 38	ND	9	OW-31	2.6
4-Methylphenol	5	10	2 / 38	ND	3,400	OW-16	3.3
Phenol	6	10	4 / 38	ND	430	OW-16	3.6

1
The values cited in this table were derived from the combined PDI and GSIP datasets. All values are
in parts per billion. Duplicate samples were averaged together. OW-1,6,7,9,11,12,14,15,18,18A,19,
19A,20,21,22,23,24A,24B,25A,25B,26B,27B,29,30A,30B,33A,33B had no detectable concentra-
tions of semivolatile compounds. The majority of this database is qualitative data, which is presented
in tabular form in Appendix .

2
I = Instrument; C = Contract Required. Values below the Instrument Detection Limit were not included
in the database.

3
The sample mean is the geometric mean, using one-half of the instrument detection limit for trace and/or
non-detected values. Note that, using this method, the mean for some constituents may be less than the
minimum value for the dataset.

Table 4.14

DESCRIPTIVE STATISTICS FOR SELECTED PHYSICAL AND CHEMICAL
PARAMETERS OF UNFILTERED GROUNDWATER SAMPLES

Groundwater/Surface Water Investigation Plan
Industri-Plex Superfund Site
Woburn, MA

CHEMICAL/PHYSICAL PARAMETER [1]	DETECTION LIMIT (I) [2]	FREQUENCY OF DETECTION	RANGE OF VALUES		LOCATION OF MAXIMUM VALUE [3]	MEAN [N = 21] [4]
			MIN	MAX		
pH	---	21 / 21	5.34	7.8	OW-10	6.5
Conductivity	20.0	21 / 21	190.00	17,880.0	OW-16	793.8
Sulfate	5.00	20 / 21	ND	1,780.0	OW-12	64.4
Sulfide	0.05	6 / 21	ND	0.2	OW-16	0.04
Total Organic Carbon (%)	0.05	21 / 21	0.71	2,730.0	OW-16	10.7
Total Phosphorus	0.05	13 / 21	ND	4.5	OW-16	0.09
Total Suspended Solids	5.00	18 / 21	ND	1,500.0	OW-22	33.9
Bicarbonate	1.00	21 / 21	5.40	11,100.0	OW-16	93.5
Chloride	5.00	19 / 21	ND	232.0	OW-21	34.8
COD	20.00	14 / 21	ND	1,500.0	OW-22	40.1

1

All units in mg/L, except for pH and total organic carbon (% dry weight).
Database includes qualitative data. Duplicate samples were averaged together.
Hardcopy of complete database presented in Appendix G.

2

The detection limit for the majority of analyses (I=instrument; CR=contract required).
The detection limit may vary for individual samples.

3

The location for the lowest pH value was OW-10 (pH = 5.34).

4

The sample mean is the geometric mean, using one-half of the instrument detection limit for trace and/or
non-detected values. Note that, using this method, the mean for some constituents may be less than the
minimum value for the dataset.

Table 4.15

HAZARD IDENTIFICATION/CONTAMINANT EVALUATION

Groundwater/Surface Water Investigation Plan
Industri-Plex Superfund Site
Woburn, MA

COMPOUND NAME	HUMAN HEALTH RISK			ECOLOGICAL EVALUATION		
	Groundwater	Surface Water	Sediment	Groundwater	Surface Water	Sediment
Aluminum	7,8,9	7,9	7,8,9	7,8,9	7,8,9	7,8,9
Antimony	X	1,2	5,8,10	5,8,9	1,3	X
Arsenic	X	X	X	A	X	X
Barium	X	7,8	7	11	7,8,9	7
Beryllium	5,8	1	2,5,8	5,8	1	2,5,8,9
Cadmium	X	1	X	7,9	1	X
Calcium	7,8,9	7,8,9	7,8,9	7,8,9	7,8,9	7,8,9
Chromium	X	X	X	11	X	X
Cobalt	5,8,9	2,3,8,9	2,7,9	5,8,9	2,3,8,9	2,8,9
Copper	7,5,8,9	2,5,8,9	7,9	A	X	X
Iron	7,9	7,8,9	7,9	7,9	7,8,9	7,9
Lead	X	X	X	11	X	X
Magnesium	7,8,9	7,8,9	2,7,8,9	7,8,9	7,8,9	2,7,8,9
Manganese	7,8,9	7,8,9	7,9	7,11	X	7,8
Mercury	X	1	X	3,5,8	1	7,8
Nickel	X	1	5,7,8	5,8	1	5,8
Potassium	7,8,9	7,9	2,7,8,9	7,8,9	7,8,9	2,7,8,9
Selenium	5,7,8	1	5,7,8	5,8,9	1	5,8
Silver	3,5,7,8,9	2,3,4,8	5,8,9	3,5,8,9	1	5,8
Sodium	7,8,9	7,8,9	7,8,9	7,8,9	7,8,9	7,8,9
Thallium	2,3,5,8	1	5,8,9,10	1	1	5,8,9
Tin	1	1	7,8,9	1	1	7,8
Vanadium	5,7,8,9	1	7,8,9	5,8,9	1	8,9
Zinc	X	7,8	7	A	X	X

1 = not detected above instrument detection limit

2 = maximum value for site area below Contract Required Detection Limit

3 = frequency of detection less than 0.07

5 = geometric mean for site area less than two times the Instrument Detection Limit

7 = compound ubiquitous, an essential nutrient, or judged to be "practically non-toxic" to humans or wildlife at concentration ranges observed

8 = site area/reference area mean ratio less than or equal to 2.0

9 = quantitative assessment not possible due to lack of adequate database

10 = location of compound necessitates exclusion from any feasible exposure scenario

11 = groundwater transport neglible

X = chosen as constituent of concern

A = will be considered as a component through groundwater discharge

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Table 4.16

HAZARD IDENTIFICATION/CONTAMINANT EVALUATION

Groundwater/Surface Water Investigation Plan
Industri-Plex Superfund Site
Woburn, MA

COMPOUND NAME	HUMAN HEALTH RISK			ECOLOGICAL EVALUATION		
	Groundwater	Surface Water	Sediment	Groundwater	Surface Water	Sediment
Acetone	10	1,2,3,5	X	7	7	9
Benzene	X	1	X	A	1	9
2-Butanone	1	1	X	1	1	7
Chlorobenzene	3,5,10	2,5,10	3,5,10	7	7	3,7
Chloroethane	2,3,10	1	1	7	1	1
Chloromethane	2,3,10	1	1	7	1	1
Chloroform	X	1	1	7	1	1
1,1-Dichloroethane	X	2,3,5	3	7	3,7	1
1,1-Dichloroethene	X	1	1	7	1	1
1,2-Dichloroethane	2,3,5	1	1	1	1	3,7
trans-1,2-Dichloroethene	X	X	3,5,10	7	7	3,7
Ethylbenzene	2,3,5	1	X	7	1	7
2-Hexanone	1	1	3,5,10	1	1	3,7
Methylene Chloride	X	X	X	7	7	7
4-Methyl-2-Pentanone	1	1	3,5,10	1	1	3,7
Tetrachloroethene	1	1	5,10	1	1	1
Toluene	X	2,10	5,10	A	2,7	7
1,1,1-Trichloroethane	X	X	1	7	7	1
Trichloroethene	X	X	2,10	7	7	7
Xylenes (total)	X	1,2,3,10	1	7	3,7	3,7

1 = not detected above instrument detection limit

2 = maximum value for site area below Contract Required Detection Limit

3 = frequency of detection less than 0.07

5 = geometric mean for site area less than two times the Instrument Detection Limit

7 = compound ubiquitous, an essential nutrient, or judged to be "practically non-toxic" to humans or wildlife at concentration ranges observed

8 = site area/reference area mean ratio less than or equal to 2.0

9 = quantitative assessment not possible due to lack of adequate database

10 = location of compound necessitates exclusion from any feasible exposure scenario

11 = groundwater transport neglible

X = chosen as constituent of concern

A = will be considered as a component through groundwater discharge

HAZARD IDENTIFICATION/CONTAMINANT EVALUATION

Groundwater/Surface Water Investigation Plan
Industri-Plex Superfund Site
Woburn, MA

COMPOUND NAME	HUMAN HEALTH RISK			ECOLOGICAL EVALUATION		
	Groundwater	Surface Water	Sediment	Groundwater	Surface Water	Sediment
Benzoic Acid	X	1	3,7	3,7,9	1	3,7,9
bis (2-Ethylhexyl)phthalate	10	X	X	7,9	7,9	X
Butylbenzylphthalate	1	1,2,3,7	3,10	1	3,7,9	3
Di-n-butylphthalate	1	1,2,3,7	1	1	3,7,9	1
Dibenzofuran	1	1	9,10	1	1	9
3,3-Dichlorobenzidine	1	1	3,10	1	1	3,9
Diethylphthalate	1	1,2,7	X	1	1	X
2,4-Dinitrotoluene	1	1	3,10	1	1	3,9
2-Methylphenol	3	1	1	3	1	1
4-Methylphenol	X	1	1	3	1	1
N-Nitrosodiphenylamine	1	1,2,3	3,10	1	3,9	3
Pentachlorophenol	1	1	3,10	1	1	9
Phenol	X	1	1	X	1	1
PAH COMPOUNDS						
Acenaphthene	3	1	1	3	1	3,7
Acenaphthylene	1	1	3,9,10	1	1	9
Anthracene	1	1	9	1	1	X
Benzo (a) anthracene	1	1	X	1	1	X
Benzo (a) pyrene	1	1	X	1	1	X
Benzo (b) fluoranthene	1	1	X	1	1	9
Benzo (g,h,i)perylene	1	1	9	1	1	9
Benzo (k) fluoranthene	1	1	X	1	1	9
Chrysene	1	1	X	1	1	X
Dibenzo (a,h) anthracene	1	1	X	1	1	X
Fluoranthene	1	1	X	1	1	X
Fluorene	1	1	3,10	1	1	3,7
Indeno (1,2,3-cd) pyrene	1	1	X	1	1	9
Naphthalene	1	1	3,10	1	1	9
Phenanthrene	1	1	5,9	1	1	X
Pyrene	1	1	X	1	1	X

1 = not detected above instrument detection limit

2 = maximum value for site area below Contract Required Detection Limit

3 = frequency of detection less than 0.07

5 = geometric mean for site area less than two times the Instrument Detection Limit

7 = compound ubiquitous, an essential nutrient, or judged to be "practically non-toxic" to
    humans or wildlife at concentration ranges observed

8 = site area/reference area mean ratio less than or equal to 2.0

9 = quantitative assessment not possible due to lack of adequate database

10 = location of compound necessitates exclusion from any feasible exposure scenario

11 = groundwater transport negligible

X = chosen as constituent of concern

A = will be considered as a component through groundwater discharge

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TABLE 4.18

TOXICITY INFORMATION
Groundwater/Surface Water Investigation Plan
Industri-Plex Superfund Site
Woburn, MA

Chemical	Inhalation CPF (mg/kg/dy)-1	Oral CPF (mg/kg/dy)-1	Weight of Evidence	Type of Cancer for Class A	Source (a)	Vehicle for Oral CPF	Inhalation RfD (mg/kg/dy)	Oral RfD (mg/kg/day)	Critical Effect	Source (a)	Vehicle for Oral RFD	RfD Uncertainty Adjustments (b)
Acetone								0.1	increased organ wt.	HEAST	gavage	1000
Anthracene			D					0.3	No effect	HEAST	gavage	3000
Antimony								0.0004	reduced lifespan	HEAST	water	1000
Arsenic	50	2	A	skin,lung	HEAST	water		0.001	keratosis	HEAST		1
Barium							0.0001	0.05	fetotoxicity	HEAST	water	1000,100
Benzene	0.029	0.029	A	leukemia	HEAST	occup.						
Benzo (a) anthracene		11.5	B2		Former CPF							
Benzo (a) pyrene	6.1	11.5	B2		Former CPF	lead				HEAST		
Benzo (b) fluoranthene		11.5	B2		Former CPF							
Benzo (k) fluoranthene		11.5	B2		Former CPF							
Benzoic acid								4	irritation	HEAST	diet	1
Beryllium	8.4	4.3	B2		HEAST	water		0.005	No effect	HEAST	water	100
Bis(2-ehtylhexyl) phthalate		0.014	B2		HEAST	diet		0.02	increased liver wt.	HEAST	diet	1000
2-Butanone (MEK)							0.09	0.05	CNS; fetotoxicity	HEAST	inhalation	1000
Cadmium	6.1		B1		HEAST	occup.		0.0005	liver;kidney	HEAST	water	10
Chloroform	0.081	0.0061	B2		HEAST	water		0.01	liver lesions	HEAST		1000
Chromium III					HEAST		0.000002	1	liver toxicity	HEAST	diet	1000
Chrysene		11.5	B2		Former CPF							
Dibenzo(a,h) anthracene	6.1	11.5	B2									
Diethyl phthalate								0.8	reduced body wt.	HEAST	diet	1000
1,1-Dichloroethane			C		HEAST		0.1	0.1	kidney damage	HEAST	inhalation	1000
1,1-Dichloroethene	0.175 (e)	0.6	C		HEAST	gavage		0.009	liver lesions	HEAST	water	1000
trans-1,2-Dichloroethene								0.02	inc. alk. phosphatase	HEAST	water	1000
Ethylbenzene			D				0.286	0.1	liver/kidney toxicity	HEAST	neat	1000
Fluoranthene								0.04	nephropathy	HEAST	gavage	3000
Indeno (1,2,3-cd) pyrene		11.5	B2		Former CPF							
Lead			B2		HEAST			0.0014	CNS effects	MCL (c)	MCL (c)	
Mercury							0.0003	0.0003	neurotoxicity;kidney	HEAST	parenteral	
Methylene Chloride	(e)	0.0075	B2		HEAST	water	0.86	0.06	liver toxicity	HEAST	water	
2- or 4-Methylphenol (cresol)								0.05	neurotoxicity;dec. body wt.	HEAST	dosed	1000
Nickel	0.84		A	lung	HEAST	occup.		0.02	reduced weight	HEAST	diet	300
Phenol								0.6	reduced fetal body wt.	HEAST	gavage	100
Pyrene								0.03	renal	HEAST	gavage	3000
Toluene			D				0.57	0.2	CNS;eye & nose irrit.	HEAST	inhalation	100
1,1,1-Trichloroethane							0.3	0.09	liver toxicity	HEAST	inhalation	1000
Trichloroethene	.00595 (e)	0.011	B2 (d)		HEAST	inhalation						
Xylenes (total)							0.086	2	CNS; irritation	HEAST	inhalation	100
Zinc								0.2	anemia	HEAST	therapeutic	10

(a) HEAST – Health Effects Assessment Summary Tables 3rd Quarter, 1990. EPA is reassessing the carcinogenic PAH, the CPF previously used for these compounds is used here for tentative risk characterization.

(b) HEAST provides no breakdown of uncertainty factors. The total value is reported for chemical information obtained from this database

(c) No RfD for lead is available. A surrogate was back calculated from the proposed MCL (10 ug/l), assuming a 10 kg child drinks 1 liter of water/day.

(d) Cancer weight of evidence for trichloroethene is reported incorrectly in HEAST. The Science Advisory Board reports the weight of evidence to be between B2 and C.

(e) Inhalation CPF for 1,1-dichloroethene and trichloroethene are back calculated from unit risk values, because CPF given in HEAST is metabolized rather than administered dose.

The unit risk value of 4.7E-7/ug/m^3 for methylene chloride was used for risk calculations, because IRIS recommends against back-calculating a CPF for this value, which is based on metabolized dose.

TABLE 4.19

LOCATION OF WELLS FOR EXPOSURE ASSESSMENT

Groundwater/Surface Water Investigation Plan
Industri-Plex Superfund Site
Woburn, MA

	RI/FS	GSIP	PDI
O N S I T E	OW-4 OW-9 OW-10 OW-11 OW-12 OW-13 OW-14 OW-15 OW-16	OW-22 OW-28	OW-23 OW-31 OW-32
O F F S I T E	OW-1 OW-1A OW-6 OW-7 OW-17 OW-18 OW-18A OW-19 OW-19A OW-20	OW-21	OW-24A OW-24B OW-25A OW-25B OW-26A OW-26B OW-27A OW-27B OW-29 OW-30A OW-30B OW-33A OW-33B OW-36 OW-37 OW-38 OW-39 OW-40 OW-42

File:Tbl4-19.wr1
Date: 5/21/91

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TABLE 4.20

EXPOSURE PATHWAYS AND SCENARIOS

Groundwater/Surface Water Investigation Plan
Industrl-Plex Superfund Site
Woburn, MA

SCENARIO/LOCATION	ROUTE OF EXPOSURE	ENVIRONMENTAL MEDIA	DATABASE CHEMICAL CLASS	SAMPLE LOCATIONS	ASSUMPTIONS (a) FREQUENCY/DURATION		RATE
DRINKING/HOUSEHOLD WATER USE	Ingestion Inhalation	Groundwater	METALS VOC's SVOC's	All off-site well locations.	PRESENT:	10 kg Child – 365 days/year, 5 years 70 kg Adult – 365 days/year, 70 years	1 l/day 2 l/day
					FUTURE:	Same as above, or lower due to dilution effects	
WADING LOWER SOUTH POND	Dermal Absorption Ingestion Ingestion	Surface Water Sediment Surface Water	METALS VOC's SVOC's	GSIP: SW–01 and SW–02 PDI: SW1/024 – 039, 041, 048	PRESENT:	45 kg Child – 12 days/year, 5 years 70 kg Adult – 12 days/year, 10 years	(b) 100 mg/day (sediment) 0.05 l/day (water)
					FUTURE:	Expected to be lower than above due to remediation, deed restriction.	
SWIMMING HALL'S BROOK RETENTION AREA	Dermal Absorption Ingestion Ingestion	Surface Water Sediment Surface Water	METALS VOC's SVOC's	GSIP: SW–09, 11, 13 PDI: no samples taken in this area	PRESENT:	45 kg Child – 12 days/year, 5 years 70 kg Adult – 12 days/year, 10 years	(b) 100 mg/day (sediment) 0.05 l/day (water)
					FUTURE:	Expected to be less than above.	
FISH INGESTION	Ingestion	Fish from Surface Water Bodies	METALS VOC's SVOC's	GSIP: SW–09, 11, 13 PDI: no samples taken for surface water	PRESENT:	45 kg Child – 48 days/year 70 kg Adult – 48 days/year, 30 years	38 g/day (avg.) 138 g/day (max.)
SEDIMENT INGESTION	Ingestion	Soil	METALS VOC's SVOC's	GSIP: SW–16 PDI: no samples taken in this area	PRESENT:	45 kg Child – 12 days/year, 5 years Adult – not considered	100 mg/day

(a) Rates taken from EPA Risk Assessment Guidance (EPA, 1989c)
(b) Dermal absorption rate calculated from permeation constant described in text.
(file:\TBL4–20.WR1)
(date:\1/6/91)
(project:\490 5054)

TABLE 4.21

1

CUMULATIVE DAILY EXPOSURE
HYPOTHETICAL EXPOSURE SCENARIO: Ingestion and Household Use of Groundwater

Groundwater/Surface Water Investigation Plan
Industri-Plex Superfund Site
Woburn, MA

0.00071 CHEMICAL	GROUNDWATER CONCENTRATIONS (ug/L)		CUMULATIVE DAILY INTAKE (mg/kg-day) FOR GROUNDWATER EXPOSURES			
			2 CDI (cancer)		2 CDI (non-cancer)	
	MAXIMUM OFF-SITE	MEAN OFF-SITE	MAXIMUM OFF-SITE	MEAN OFF-SITE	MAXIMUM OFF-SITE	MEAN OFF-SITE
Acetone	0	1.005	0.00E+00	2.87E-05	0.00E+00	1.00E-04
Antimony	27.4	18.9	7.83E-04	5.39E-04	2.74E-03	1.89E-03
Arsenic	209	7.1	5.97E-03	2.04E-04	2.09E-02	7.13E-04
Barium	505	15.2	1.44E-02	4.34E-04	5.05E-02	1.52E-03
Benzene	2,000	1.0	5.71E-02	2.73E-05	2.00E-01	9.55E-05
Benzoic acid	0	12.5	0.00E+00	3.57E-04	0.00E+00	1.25E-03
Cadmium	27.4	3.4	7.83E-04	9.68E-05	2.74E-03	3.39E-04
Chloroform	2	0.5	5.71E-05	1.49E-05	2.00E-04	5.21E-05
Chromium (III)	160	5.6	4.57E-03	1.60E-04	1.60E-02	5.59E-04
1,1-Dichloroethane	6	0.7	1.71E-04	2.06E-05	6.00E-04	7.22E-05
1,1-Dichloroethene	8	0.5	2.29E-04	1.49E-05	8.00E-04	5.21E-05
trans-1,2-Dichloroethylene	28	0.6	8.00E-04	1.78E-05	2.80E-03	6.22E-05
Lead	31.2	2.8	8.91E-04	8.08E-05	3.12E-03	2.83E-04
Mercury	0.59	0.1	1.69E-05	3.03E-06	5.90E-05	1.06E-05
4-Methylphenol (p-cresol)	0	2.5	0.00E+00	7.14E-05	0.00E+00	2.50E-04
Methylene Chloride	23	1.2	6.57E-04	3.45E-05	2.30E-03	1.21E-04
Nickel	83.4	9.5	2.38E-03	2.72E-04	8.34E-03	9.53E-04
Phenol	430	3.2	1.23E-02	9.18E-05	4.30E-02	3.21E-04
Toluene	4	0.6	1.14E-04	1.82E-05	4.00E-04	6.38E-05
1,1,1-Trichloroethane	26	0.6	7.43E-04	1.82E-05	2.60E-03	6.38E-05
Trichloroethene	110	0.8	3.14E-03	2.34E-05	1.10E-02	8.18E-05
Xylenes (total)	13	0.6	3.71E-04	1.76E-05	1.30E-03	6.15E-05
Zinc	8430	68.9	2.41E-01	1.97E-03	8.43E-01	6.89E-03

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Sample calculations and exposure parameters are given in Appendix G. Cancer calculation is for lifetime exposure, while exposure for determining non-cancer impacts is calculated for a child, as this will maximize the estimated dose

2

NOTE: CDI is for ingestion only (2 liters/day), EPA estimates exposure from household use to be approximately equal to that produced by ingestion.

TABLE 4.22

CUMULATIVE DAILY EXPOSURE (a)
HYPOTHETICAL EXPOSURE SCENARIO: Wading In Lower South Pond (Children)

Groundwater/Surface Water Investigation Plan
Industri-Plex Superfund Site
Woburn, MA

Chemical	MEAN CONCENTRATIONS Surface Water (ug/L)	MEAN CONCENTRATIONS Sediment (mg/kg)	CDI (Cancer) Ingestion of Surface Water	CDI (Cancer) Sediment Ingestion	CDI (Cancer) Dermal Absorbtion	CDI (Cancer) TOTAL	CDI (Non-Cancer) Ingestion of Surface Water	CDI (Non-Cancer) Sediment Ingestion	CDI (Non-Cancer) Dermal Absorbtion	CDI (Non-Cancer) TOTAL
Acetone		1.0	0.00E+00	5.22E-09	0.00E+00	5.22E-09	0.00E+00	7.31E-08	0.00E+00	7.31E-08
Arsenic	6.4	55.7	4.34E-08	2.91E-07	0.00E+00	3.34E-07	6.08E-07	4.07E-06	0.00E+00	4.68E-06
Benzene		0.5	0.00E+00	2.61E-09	0.00E+00	2.61E-09	0.00E+00	3.65E-08	0.00E+00	3.65E-08
Benzo (a) anthracene		36.1	0.00E+00	1.89E-07	0.00E+00	1.89E-07	0.00E+00	2.64E-06	0.00E+00	2.64E-06
Benzo (a) pyrene		30.0	0.00E+00	1.57E-07	0.00E+00	1.57E-07	0.00E+00	2.19E-06	0.00E+00	2.19E-06
Benzo (b) fluoranthene		38.7	0.00E+00	2.02E-07	0.00E+00	2.02E-07	0.00E+00	2.83E-06	0.00E+00	2.83E-06
Benzo (k) fluoranthene		38.7	0.00E+00	2.02E-07	0.00E+00	2.02E-07	0.00E+00	2.83E-06	0.00E+00	2.83E-06
bis(2-ethylhexyl)phthalate		17.9	0.00E+00	9.34E-08	0.00E+00	9.34E-08	0.00E+00	1.31E-06	0.00E+00	1.31E-06
2-Butanone		0.5	0.00E+00	2.61E-09	0.00E+00	2.61E-09	0.00E+00	3.65E-08	0.00E+00	3.65E-08
Cadmium		1.1	0.00E+00	5.74E-09	0.00E+00	5.74E-09	0.00E+00	8.04E-08	0.00E+00	8.04E-08
Chromium	3.7	89.9	2.51E-08	4.69E-07	0.00E+00	4.94E-07	3.51E-07	6.57E-06	0.00E+00	6.92E-06
Chrysene		36.3	0.00E+00	1.90E-07	0.00E+00	1.90E-07	0.00E+00	2.65E-06	0.00E+00	2.65E-06
trans-1,2-Dichloroethylene			0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Dibenzo (a,h) anthracene		1.5	0.00E+00	7.83E-09	0.00E+00	7.83E-09	0.00E+00	1.10E-07	0.00E+00	1.10E-07
Diethylphthalate		2.0	0.00E+00	1.04E-08	0.00E+00	1.04E-08	0.00E+00	1.46E-07	0.00E+00	1.46E-07
Ethylbenzene		0.5	0.00E+00	2.61E-09	0.00E+00	2.61E-09	0.00E+00	3.65E-08	0.00E+00	3.65E-08
Fluoranthene		47.4	0.00E+00	2.48E-07	0.00E+00	2.48E-07	0.00E+00	3.47E-06	0.00E+00	3.47E-06
Indeno (1,2,3-cd) pyrene		28.6	0.00E+00	1.49E-07	0.00E+00	1.49E-07	0.00E+00	2.09E-06	0.00E+00	2.09E-06
Lead	2.6	123.4	1.74E-08	6.44E-07	0.00E+00	6.61E-07	2.44E-07	9.01E-06	0.00E+00	9.26E-06
Mercury		0.3	0.00E+00	1.57E-09	0.00E+00	1.57E-09	0.00E+00	2.19E-08	0.00E+00	2.19E-08
Methylene Chloride		6.5	0.00E+00	3.38E-08	0.00E+00	3.38E-08	0.00E+00	4.73E-07	0.00E+00	4.73E-07
Pyrene		47.4	0.00E+00	2.48E-07	0.00E+00	2.48E-07	0.00E+00	3.47E-06	0.00E+00	3.47E-06

(a) Sample calculations and exposure parameters are given in Appendix G.

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TABLE 4.23

CUMULATIVE DAILY EXPOSURE (a)
HYPOTHETICAL EXPOSURE SCENARIO: Wading in Lower South Pond (Adults)

Groundwater/Surface Water Investigation Plan
Industri–Plex Superfund Site
Woburn, MA

Chemical	MEAN CONCENTRATIONS Surface Water (ug/L)	MEAN CONCENTRATIONS Sediment (mg/kg)	CDI (Cancer) Ingestion of Surface Water	CDI (Cancer) Sediment Ingestion	CDI (Cancer) Dermal Absorbtion	CDI (Cancer) TOTAL	CDI (Non-Cancer) Ingestion of Surface Water	CDI (Non-Cancer) Sediment Ingestion	CDI (Non-Cancer) Dermal Absorbtion	CDI (Non-Cancer) TOTAL
Acetone		1.0	0.00E+00	3.35E-09	0.00E+00	3.35E-09	0.00E+00	2.35E-08	0.00E+00	2.35E-08
Arsenic	6.4	55.7	5.58E-08	1.87E-07	0.00E+00	2.43E-07	3.91E-07	1.31E-06	0.00E+00	1.70E-06
Benzene		0.5	0.00E+00	1.68E-09	0.00E+00	1.68E-09	0.00E+00	1.17E-08	0.00E+00	1.17E-08
Benzo (a) anthracene		36.1	0.00E+00	1.21E-07	0.00E+00	1.21E-07	0.00E+00	8.48E-07	0.00E+00	8.48E-07
Benzo (a) pyrene		30.0	0.00E+00	1.01E-07	0.00E+00	1.01E-07	0.00E+00	7.05E-07	0.00E+00	7.05E-07
Benzo (b) fluoranthene		38.7	0.00E+00	1.30E-07	0.00E+00	1.30E-07	0.00E+00	9.10E-07	0.00E+00	9.10E-07
Benzo (k) fluoranthene		38.7	0.00E+00	1.30E-07	0.00E+00	1.30E-07	0.00E+00	9.10E-07	0.00E+00	9.10E-07
bis(2-ethylhexyl)phthalate		17.9	0.00E+00	6.00E-08	0.00E+00	6.00E-08	0.00E+00	4.20E-07	0.00E+00	4.20E-07
2-Butanone		0.5	0.00E+00	1.68E-09	0.00E+00	1.68E-09	0.00E+00	1.17E-08	0.00E+00	1.17E-08
Cadmium		1.1	0.00E+00	3.69E-09	0.00E+00	3.69E-09	0.00E+00	2.58E-08	0.00E+00	2.58E-08
Chromium	3.7	89.9	3.23E-08	3.01E-07	0.00E+00	3.34E-07	2.26E-07	2.11E-06	0.00E+00	2.34E-06
Chrysene		36.3	0.00E+00	1.22E-07	0.00E+00	1.22E-07	0.00E+00	8.53E-07	0.00E+00	8.53E-07
trans-1,2-Dichloroethylene			0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Dibenzo (a,h) anthracene		1.5	0.00E+00	5.03E-09	0.00E+00	5.03E-09	0.00E+00	3.52E-08	0.00E+00	3.52E-08
Diethylphthalate		2.0	0.00E+00	6.71E-09	0.00E+00	6.71E-09	0.00E+00	4.70E-08	0.00E+00	4.70E-08
Ethylbenzene		0.5	0.00E+00	1.68E-09	0.00E+00	1.68E-09	0.00E+00	1.17E-08	0.00E+00	1.17E-08
Fluoranthene		47.4	0.00E+00	1.59E-07	0.00E+00	1.59E-07	0.00E+00	1.11E-06	0.00E+00	1.11E-06
Indeno (1,2,3-cd) pyrene		28.6	0.00E+00	9.61E-08	0.00E+00	9.61E-08	0.00E+00	6.72E-07	0.00E+00	6.72E-07
Lead	2.6	123.4	2.24E-08	4.14E-07	0.00E+00	4.36E-07	1.57E-07	2.90E-06	0.00E+00	3.05E-06
Mercury		0.3	0.00E+00	1.01E-09	0.00E+00	1.01E-09	0.00E+00	7.05E-09	0.00E+00	7.05E-09
Methylene Chloride		6.5	0.00E+00	2.17E-08	0.00E+00	2.17E-08	0.00E+00	1.52E-07	0.00E+00	1.52E-07
Pyrene		47.4	0.00E+00	1.59E-07	0.00E+00	1.59E-07	0.00E+00	1.11E-06	0.00E+00	1.11E-06
1,1,1-Trichloroethane			0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Trichloroethene			0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00

(a) Sample calculations and exposure parameters are given in Appendix G.

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TABLE 4.24

CUMULATIVE DAILY EXPOSURE (a)
HYPOTHETICAL EXPOSURE SCENARIO: Swimming in Hall's Brook Retention Area (Children)

Groundwater/Surface Water Investigation Plan
Industri-Plex Superfund Site
Woburn, MA

Chemical	MEAN CONCENTRATIONS Surface Water (ug/L)	Sediment (mg/kg)	Ingestion of Surface Water	CDI (Cancer) Sediment Ingestion	Dermal Absorbtion	TOTAL	Ingestion of Surface water	CDI (Non-Cancer) Sediment Ingestion	Dermal Absorbtion	TOTAL
Acetone		57.4	0.00E+00	3.00E-07	0.00E+00	3.00E-07	0.00E+00	4.19E-06	0.00E+00	4.19E-06
Arsenic	4.2	689.9	2.83E-08	3.60E-06	0.00E+00	3.63E-06	3.97E-07	5.04E-05	0.00E+00	5.08E-05
Benzene		406.6	0.00E+00	2.12E-06	0.00E+00	2.12E-06	0.00E+00	2.97E-05	0.00E+00	2.97E-05
Benzo (a) anthracene		173.5	0.00E+00	9.05E-07	0.00E+00	9.05E-07	0.00E+00	1.27E-05	0.00E+00	1.27E-05
Benzo (a) pyrene		159.4	0.00E+00	8.32E-07	0.00E+00	8.32E-07	0.00E+00	1.16E-05	0.00E+00	1.16E-05
Benzo (b) fluoranthene		158.2	0.00E+00	8.26E-07	0.00E+00	8.26E-07	0.00E+00	1.16E-05	0.00E+00	1.16E-05
Benzo (k) fluoranthene		162.9	0.00E+00	8.50E-07	0.00E+00	8.50E-07	0.00E+00	1.19E-05	0.00E+00	1.19E-05
bis(2-ethylhexyl)phthalate	3.6	1,654.0	2.44E-08	8.63E-06	7.25E-07	9.38E-06	3.42E-07	1.21E-04	1.02E-05	1.31E-04
2-Butanone		11.9	0.00E+00	6.21E-08	0.00E+00	6.21E-08	0.00E+00	8.69E-07	0.00E+00	8.69E-07
Cadmium		1.7	0.00E+00	8.87E-09	0.00E+00	8.87E-09	0.00E+00	1.24E-07	0.00E+00	1.24E-07
Chromium	2.8	235.2	1.92E-08	1.23E-06	0.00E+00	1.25E-06	2.69E-07	1.72E-05	0.00E+00	1.75E-05
Chrysene		229.9	0.00E+00	1.20E-06	0.00E+00	1.20E-06	0.00E+00	1.68E-05	0.00E+00	1.68E-05
trans-1,2-Dichloroethylene	3.5		2.40E-08	0.00E+00	8.86E-08	1.13E-07	3.35E-07	0.00E+00	1.24E-06	1.58E-06
Dibenzo (a,h) anthracene		1.5	0.00E+00	7.83E-09	0.00E+00	7.83E-09	0.00E+00	1.10E-07	0.00E+00	1.10E-07
Diethylphthalate		199.8	0.00E+00	1.04E-06	0.00E+00	1.04E-06	0.00E+00	1.46E-05	0.00E+00	1.46E-05
Ethylbenzene		5.6	0.00E+00	2.92E-08	0.00E+00	2.92E-08	0.00E+00	4.09E-07	0.00E+00	4.09E-07
Fluoranthene		341.5	0.00E+00	1.78E-06	0.00E+00	1.78E-06	0.00E+00	2.49E-05	0.00E+00	2.49E-05
Indeno (1,2,3-cd) pyrene		19.7	0.00E+00	1.03E-07	0.00E+00	1.03E-07	0.00E+00	1.44E-06	0.00E+00	1.44E-06
Lead	4.1	132.3	2.76E-08	6.90E-07	0.00E+00	7.18E-07	3.87E-07	9.67E-06	0.00E+00	1.01E-05
Mercury		1.3	0.00E+00	6.78E-09	0.00E+00	6.78E-09	0.00E+00	9.50E-08	0.00E+00	9.50E-08
Methylene Chloride	7.7	3.4	5.19E-08	1.77E-08	1.30E-07	1.99E-07	7.27E-07	2.48E-07	1.82E-06	2.79E-06
Pyrene		295.3	0.00E+00	1.54E-06	0.00E+00	1.54E-06	0.00E+00	2.16E-05	0.00E+00	2.16E-05

(a)Sample calculations and exposure parameters are given in Appendix G.

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TABLE 4.25

CUMULATIVE DAILY EXPOSURE (a)
HYPOTHETICAL EXPOSURE SCENARIO: Swimming in Hall's Brook Retention Area (Adult)

Groundwater/Surface Water Investigation Plan
Industri-Plex Superfund Site
Woburn, MA

Chemical	MEAN CONCENTRATIONS Surface Water (ug/L)	Sediment (mg/kg)	Ingestion of Surface Water	CDI (Cancer) Sediment Ingestion	Dermal Absorbtion	TOTAL	Ingestion of Surface water	CDI (Non-Cancer) Sediment Ingestion	Dermal Absorbtion	TOTAL
Acetone	1.0	57.4	8.77E-09	1.93E-07	3.18E-09	2.05E-07	6.14E-08	1.35E-06	2.23E-08	1.43E-06
Arsenic	4.2	689.9	3.64E-08	2.31E-06	0.00E+00	2.35E-06	2.55E-07	1.62E-05	0.00E+00	1.65E-05
Benzene		406.6	0.00E+00	1.36E-06	0.00E+00	1.36E-06	0.00E+00	9.55E-06	0.00E+00	9.55E-06
Benzo (a) anthracene		173.5	0.00E+00	5.82E-07	0.00E+00	5.82E-07	0.00E+00	4.07E-06	0.00E+00	4.07E-06
Benzo (a) pyrene		159.4	0.00E+00	5.35E-07	0.00E+00	5.35E-07	0.00E+00	3.74E-06	0.00E+00	3.74E-06
Benzo (b) fluoranthene		158.2	0.00E+00	5.31E-07	0.00E+00	5.31E-07	0.00E+00	3.72E-06	0.00E+00	3.72E-06
Benzo (k) fluoranthene		162.9	0.00E+00	5.46E-07	0.00E+00	5.46E-07	0.00E+00	3.83E-06	0.00E+00	3.83E-06
bis(2-ethylhexyl)phthalate	3.6	1,654.0	3.14E-08	5.55E-06	1.14E-06	6.72E-06	2.20E-07	3.88E-05	7.98E-06	4.70E-05
2-Butanone		11.9	0.00E+00	3.99E-08	0.00E+00	3.99E-08	0.00E+00	2.79E-07	0.00E+00	2.79E-07
Cadmium		1.7	0.00E+00	5.70E-09	0.00E+00	5.70E-09	0.00E+00	3.99E-08	0.00E+00	3.99E-08
Chromium	2.8	235.2	2.47E-08	7.89E-07	0.00E+00	8.14E-07	1.73E-07	5.52E-06	0.00E+00	5.70E-06
Chrysene		229.9	0.00E+00	7.71E-07	0.00E+00	7.71E-07	0.00E+00	5.40E-06	0.00E+00	5.40E-06
trans-1,2-Dichloroethylene	3.5		3.08E-08	0.00E+00	1.39E-07	1.70E-07	2.16E-07	0.00E+00	9.74E-07	1.19E-06
Dibenzo (a,h) anthracene		1.5								
Diethylphthalate		199.8	0.00E+00	6.70E-07	0.00E+00	6.70E-07	0.00E+00	4.69E-06	0.00E+00	4.69E-06
Ethylbenzene		5.6	0.00E+00	1.88E-08	0.00E+00	1.88E-08	0.00E+00	1.32E-07	0.00E+00	1.32E-07
Fluoranthene		341.5	0.00E+00	1.15E-06	0.00E+00	1.15E-06	0.00E+00	8.02E-06	0.00E+00	8.02E-06
Indeno (1,2,3-cd) pyrene		19.7	0.00E+00	6.61E-08	0.00E+00	6.61E-08	0.00E+00	4.63E-07	0.00E+00	4.63E-07
Lead	4.1	132.3	3.55E-08	4.44E-07	0.00E+00	4.79E-07	2.49E-07	3.11E-06	0.00E+00	3.36E-06
Mercury		1.3	0.00E+00	4.36E-09	0.00E+00	4.36E-09	0.00E+00	3.05E-08	0.00E+00	3.05E-08
Methylene Chloride	7.7	3.4	6.67E-08	1.14E-08	2.04E-07	2.82E-07	4.67E-07	7.98E-08	1.43E-06	1.97E-06
Pyrene		295.3	0.00E+00	9.91E-07	0.00E+00	9.91E-07	0.00E+00	6.93E-06	0.00E+00	6.93E-06

(a)Sample calculations and exposure parameters are given in Appendix G.

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(project:\490 5054)

TABLE 4.26

CUMULATIVE DAILY EXPOSURE (a)
HYPOTHETICAL EXPOSURE SCENARIO: Sediment ingestion at SW-16.

Groundwater/Surface Water Investigation Plan
Industri-Plex Superfund Site
Woburn, MA

Chemical	CONCENTRATION AT SW-16 (sediment) (mg/kg)	CUMULATIVE DAILY INTAKE (mg/kg-day) FOR SEDIMENT EXPOSURE	
		CDI (Cancer)	CDI (Non-Cancer)
Acetone	0.170	2.22E-09	3.11E-08
Arsenic	928	1.21E-05	1.69E-04
Benzo (a) anthracene	15	1.96E-07	2.74E-06
Benzo (a) pyrene	12	1.57E-07	2.19E-06
Benzo (b) fluoranthene	27	3.52E-07	4.93E-06
Benzo (k) fluoranthene	27	3.52E-07	4.93E-06
Beryllium	1.1	1.44E-08	2.01E-07
bis(2-ethylhexyl)phthalate	3.5	4.57E-08	6.39E-07
Cadmium	23.4	3.05E-07	4.27E-06
Chromium	140	1.83E-06	2.56E-05
Chrysene	13	1.70E-07	2.37E-06
Dibenzo (a,h) anthracene	3.1	4.04E-08	5.66E-07
Fluoranthene	22	2.87E-07	4.02E-06
Indeno (1,2,3-cd) pyrene	5.8	7.57E-08	1.06E-06
Lead	354	4.62E-06	6.47E-05
Mercury	0.4	5.22E-09	7.31E-08
Pyrene	22	2.87E-07	4.02E-06

(a)Sample calculations and exposure parameters are given in Appendix G.

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(project:\490 5054)

ROUX ASSOCIATES INC

TABLE 4.27

CUMULATIVE DAILY EXPOSURE (a)
HYPOTHETICAL EXPOSURE SCENARIO: Ingestion of Fish from Hall's Brook
(average ingestion rate)

Groundwater/Surface Water Investigation Plan
Industri-Plex Superfund Site
Woburn, MA

Chemical	MEAN WATER CONCENTRATION (ug/l)	CUMULATIVE DAILY INTAKE (mg/kg-day)	
		CDI (Cancer)	CDI (Non-Cancer)
Arsenic	4.2	5.11E-08	1.85E-07
bis(2-ethylhexyl)phthalate	3.6	1.11E-08	4.04E-08
Chromium	2.8	1.39E-07	5.04E-07
trans-1,2-Dichloroethylene	3.5	1.73E-08	6.27E-08
Lead	4.1	6.10E-07	2.21E-06
Methylene Chloride	7.7	1.17E-07	4.25E-07
1,1,1-Trichloroethane	2.6	4.51E-08	1.64E-07
Trichloroethene	2.5	8.11E-08	2.94E-07

(a) Sample calculations and exposure parameters are given in Appendix G.

(file:\TBL4-27.WR1)

(date:\5/21/91)

(project:\490 5046)

TABLE 4.28

CUMULATIVE DAILY EXPOSURE (a)
HYPOTHETICAL EXPOSURE SCENARIO: Ingestion of Fish from Hall's Brook
(for maximum fish ingestion rate)

Groundwater/Surface Water Investigation Plan
Industri-Plex Superfund Site
Woburn, MA

Chemical	MEAN WATER CONCENTRATION (ug/l)	CUMULATIVE DAILY INTAKE (mg/kg-day)	
		CDI (Cancer)	CDI (Non-Cancer)
Arsenic	4.2	1.78E-06	6.44E-06
bis(2-ethylhexyl)phthalate	3.6	3.86E-07	1.40E-06
Chromium	2.8	4.82E-06	1.75E-05
trans-1,2-Dichloroethylene	3.5	6.00E-07	2.18E-06
Lead	4.1	2.12E-05	7.69E-05
Methylene Chloride	7.7	4.07E-06	1.48E-05
1,1,1-Trichloroethane	2.6	1.56E-06	5.68E-06
Trichloroethene	2.5	2.82E-06	1.02E-05

(a) Sample calculations and exposure parameters are given in Appendix G.

(file:\TBL4-28.WR1)

(date:\5/21/91)

(project:\490 5048)

TABLE 4.29

1

RISK CHARACTERIZATION
HYPOTHETICAL EXPOSURE SCENARIO: Ingestion and Household Use of Groundwater

Groundwater/Surface Water Investigation Plan
Industri-Plex Superfund Site
Woburn, MA

	RISK CHARACTERIZATION FOR GROUNDWATER EXPOSURES							
	CDI (cancer) 2		CANCER RISK		CDI (non-cancer) 2		HAZARD INDEX	
CHEMICAL	MAXIMUM OFF-SITE	MEAN OFF-SITE	MAXIMUM OFF-SITE	MEAN OFF-SITE	MAXIMUM OFF-SITE	MEAN OFF-SITE	MAXIMUM OFF-SITE	MEAN OFF-SITE
Acetone	0.00E+00	7.17E-05			0.00E+00	3.59E-05	0.0E+00	2.5E-03
Arsenic	4.71E-03	2.18E-04	9.4E-03	4.4E-04	1.65E-02	1.09E-04	1.2E+01	7.6E-02
Benzene	3.80E-02	5.72E-05	7.7E-03	1.2E-05	1.33E-01	2.86E-05	0.0E+00	0.0E+00
Benzoic acid	0.00E+00	3.57E-04			0.00E+00	1.79E-04	0.0E+00	4.5E-05
Beryllium	4.57E-05	1.54E-05	2.0E-04	6.6E-05	1.60E-04	7.72E-06	3.2E-02	1.5E-03
Cadmium	7.83E-04	9.22E-05			2.74E-03	4.61E-05	5.5E+00	9.2E-02
Chloroform	5.71E-05	4.37E-05	2.8E-05	2.1E-05	2.00E-04	2.18E-05	1.4E-01	1.5E-02
Chromium	1.90E-03	1.35E-04			6.65E-03	6.74E-05	6.7E-03	6.7E-05
1,1-Dichloroethane	1.71E-04	5.18E-05			6.00E-04	2.59E-05	4.2E-02	1.8E-03
1,1-Dichloroethene	2.29E-04	4.81E-05	1.8E-03	3.8E-04	8.00E-04	2.41E-05	6.2E-01	1.9E-02
trans-1,2-Dichloroethylene	8.00E-04	5.07E-05			2.80E-03	2.54E-05	9.8E-01	8.9E-03
Lead	8.91E-04	1.15E-04			3.12E-03	5.76E-05	2.2E+00	4.0E-02
Mercury	0.00E+00	0.00E+00			0.00E+00	0.00E+00	0.0E+00	0.0E+00
2-Methylphenol (o-cresol)	0.00E+00	7.14E-05			0.00E+00	3.57E-05	0.0E+00	7.1E-04
4-Methylphenol (p-cresol)	0.00E+00	7.14E-05			0.00E+00	3.57E-05	0.0E+00	7.1E-04
Methylene Chloride	6.57E-04	8.56E-05	6.0E-05	7.8E-06	2.30E-03	4.28E-05	4.3E-02	8.0E-04
Nickel	2.05E-03	2.70E-04			7.19E-03	1.35E-04	3.6E-01	6.8E-03
Phenol	1.23E-02	9.18E-05			4.30E-02	4.59E-05	7.2E-02	7.7E-05
Toluene	1.14E-04	4.45E-05			4.00E-04	2.22E-05	9.3E-03	5.2E-04
1,1,1-Trichloroethane	7.43E-04	5.50E-05			2.60E-03	2.75E-05	8.1E-02	8.6E-04
Trichloroethene	3.14E-03	6.98E-05	3.6E-04	7.9E-06	1.10E-02	3.49E-05	0.0E+00	0.0E+00
Xylenes (total)	1.86E-04	4.72E-05			6.50E-04	2.36E-05	1.3E-02	4.8E-04
	TOTALS		2.0E-02	9.3E-04		TOTALS	2.2E+01	2.7E-01

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(DATE: 1/13/91)

(project:\480 6064)

1
Sample calculations and exposure parameters are given in Appendix G.

2
NOTE: CDI is for ingestion only (2 liters/day). For household water use, the CDI = (6 X CDI) + CDI

TABLE 4.30

RISK CHARACTERIZATION
HYPOTHETICAL EXPOSURE SCENARIO:
Wading in Lower South Pond (Children)

Groundwater/Surface Water Investigation Plan
Industri-Plex Superfund Site
Woburn, MA

Chemical	RISK CHARACTERIZATION FOR LSP EXPOSURES			
	CDI (Cancer)	CANCER RISK	CDI (Non-Cancer)	HAZARD INDEX
Acetone	5.22E-09	0.0E+00	7.31E-08	7.3E-07
Arsenic	3.34E-07	6.7E-07	4.68E-06	4.7E-03
Benzene	2.61E-09	7.6E-11	3.65E-08	0.0E+00
Benzo (a) anthracene	1.89E-07	2.2E-06	2.64E-06	0.0E+00
Benzo (a) pyrene	1.57E-07	1.8E-06	2.19E-06	0.0E+00
Benzo (b) fluoranthene	2.02E-07	2.3E-06	2.83E-06	0.0E+00
Benzo (k) fluoranthene	2.02E-07	2.3E-06	2.83E-06	0.0E+00
bis(2-ethylhexyl)phthalate	9.34E-08	1.3E-09	1.31E-06	0.0E+00
2-Butanone	2.61E-09	0.0E+00	3.65E-08	7.3E-07
Cadmium	5.74E-09	0.0E+00	8.04E-08	1.6E-04
Chromium	4.94E-07	0.0E+00	6.92E-06	6.9E-06
Chrysene	1.90E-07	2.2E-06	2.65E-06	0.0E+00
trans-1,2-Dichloroethylene	0.00E+00	0.0E+00	0.00E+00	0.0E+00
Dibenzo (a,h) anthracene	7.83E-09	9.0E-08	1.10E-07	0.0E+00
Diethylphthalate	1.04E-08	0.0E+00	1.46E-07	1.8E-07
Ethylbenzene	2.61E-09	0.0E+00	3.65E-08	3.7E-07
Fluoranthene	2.48E-07	0.0E+00	3.47E-06	8.7E-05
Indeno (1,2,3-cd) pyrene	1.49E-07	1.7E-06	2.09E-06	0.0E+00
Lead	6.61E-07	0.0E+00	9.26E-06	6.5E-03
Mercury	1.57E-09	0.0E+00	2.19E-08	7.3E-05
Methylene Chloride	3.38E-08	2.5E-10	4.73E-07	7.9E-06
Pyrene	2.48E-07	0.0E+00	3.47E-06	1.2E-04
TOTALS		1.3E-05		1.2E-02

(a) Sample calculations and exposure parameters are given in Appendix G.

(file:\TBL4-30.WR1)

(date:5/21/91)

(project:\490 5046)

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TABLE 4.31

RISK CHARACTERIZATION
HYPOTHETICAL EXPOSURE SCENARIO:
Wading in Lower South Pond (Adults)

Groundwater/Surface Water Investigation Plan
Industri-Plex Superfund Site
Woburn, MA

Chemical	RISK CHARACTERIZATION FOR LSP EXPOSURE			
	CDI (Cancer)	CANCER RISK	CDI (Non-Cancer)	HAZARD INDEX
Acetone	3.35E-09	0.0E+00	2.35E-08	2.3E-07
Arsenic	2.43E-07	4.9E-07	1.70E-06	1.7E-03
Benzene	1.68E-09	4.9E-11	1.17E-08	0.0E+00
Benzo (a) anthracene	1.21E-07	1.4E-06	8.48E-07	0.0E+00
Benzo (a) pyrene	1.01E-07	1.2E-06	7.05E-07	0.0E+00
Benzo (b) fluoranthene	1.30E-07	1.5E-06	9.10E-07	0.0E+00
Benzo (k) fluoranthene	1.30E-07	1.5E-06	9.10E-07	0.0E+00
bis(2-ethylhexyl)phthalate	6.00E-08	8.4E-10	4.20E-07	0.0E+00
2-Butanone	1.68E-09	0.0E+00	1.17E-08	2.3E-07
Cadmium	3.69E-09	0.0E+00	2.58E-08	5.2E-05
Chromium	3.34E-07	0.0E+00	2.34E-06	2.3E-06
Chrysene	1.22E-07	1.4E-06	8.53E-07	0.0E+00
trans-1,2-Dichloroethylene	0.00E+00	0.0E+00	0.00E+00	0.0E+00
Dibenzo (a,h) anthracene	5.03E-09	5.8E-08	3.52E-08	0.0E+00
Diethylphthalate	6.71E-09	0.0E+00	4.70E-08	5.9E-08
Ethylbenzene	1.68E-09	0.0E+00	1.17E-08	1.2E-07
Fluoranthene	1.59E-07	0.0E+00	1.11E-06	2.8E-05
Indeno (1,2,3-cd) pyrene	9.61E-08	1.1E-06	6.72E-07	0.0E+00
Lead	4.36E-07	0.0E+00	3.05E-06	2.1E-03
Mercury	1.01E-09	0.0E+00	7.05E-09	2.3E-05
Methylene Chloride	2.17E-08	1.6E-10	1.52E-07	2.5E-06
Pyrene	1.59E-07	0.0E+00	1.11E-06	3.7E-05
1,1,1-Trichloroethane	0.00E+00	0.0E+00	0.00E+00	0.0E+00
Trichloroethene	0.00E+00	0.0E+00	0.00E+00	0.0E+00
TOTALS		8.6E-06		4.0E-03

(a) Sample calculations and exposure parameters are given in Appendix G.

(file:\TBL4-31.WR1)

(date:6/21/91)

(project:\490 5046)

TABLE 4.32

RISK CHARACTERIZATION
HYPOTHETICAL EXPOSURE SCENARIO:
Swimming in Hall's Brook Holding Area (Children)

Groundwater/Surface Water Investigation Plan
Industri-Plex Superfund Site
Woburn, MA

Chemical	RISK CHARACTERIZATION FOR HBHA			
	CDI (Cancer)	CANCER RISK	CDI (Non-Cancer)	HAZARD INDEX
Acetone	3.00E-07	0.0E+00	4.19E-06	4.2E-05
Arsenic	3.63E-06	7.3E-06	5.08E-05	5.1E-02
Benzene	2.12E-06	6.2E-08	2.97E-05	0.0E+00
Benzo (a) anthracene	9.05E-07	1.0E-05	1.27E-05	0.0E+00
Benzo (a) pyrene	8.32E-07	9.6E-06	1.16E-05	0.0E+00
Benzo (b) fluoranthene	8.26E-07	9.5E-06	1.16E-05	0.0E+00
Benzo (k) fluoranthene	8.50E-07	9.8E-06	1.19E-05	0.0E+00
bis(2-ethylhexyl)phthalate	9.38E-06	1.3E-07	1.31E-04	0.0E+00
2-Butanone	6.21E-08	0.0E+00	8.69E-07	1.7E-05
Cadmium	8.87E-09	0.0E+00	1.24E-07	2.5E-04
Chromium	1.25E-06	0.0E+00	1.75E-05	1.7E-05
Chrysene	1.20E-06	1.4E-05	1.68E-05	0.0E+00
trans-1,2-Dichloroethylene	1.13E-07	0.0E+00	1.58E-06	7.9E-05
Dibenzo (a,h) anthracene	7.83E-09	9.0E-08	1.10E-07	0.0E+00
Diethylphthalate	1.04E-06	0.0E+00	1.46E-05	1.8E-05
Ethylbenzene	2.92E-08	0.0E+00	4.09E-07	4.1E-06
Fluoranthene	1.78E-06	0.0E+00	2.49E-05	6.2E-04
Indeno (1,2,3-cd) pyrene	1.03E-07	1.2E-06	1.44E-06	0.0E+00
Lead	7.18E-07	0.0E+00	1.01E-05	7.0E-03
Mercury	6.78E-09	0.0E+00	9.50E-08	3.2E-04
Methylene Chloride	1.99E-07	1.5E-09	2.79E-06	4.7E-05
Pyrene	1.54E-06	0.0E+00	2.16E-05	7.2E-04
TOTALS		6.2E-05		6.0E-02

(a)Sample calculations and exposure parameters are given in Appendix G.

(file:\TBL4-32.WR1)

(date:5/21/91)

(project:\490 5046)

TABLE 4.33

CUMULATIVE DAILY EXPOSURE (a)
HYPOTHETICAL EXPOSURE SCENARIO:
Swimming in Hall's Brook Retention Area (Adult)

Groundwater/Surface Water Investigation Plan
Industri-Plex Superfund Site
Woburn, MA

Chemical	RISK CHARACTERIZATION FOR HBHA			
	CDI (Cancer)	CANCER RISK	CDI (Non-Cancer)	HAZARD INDEX
Acetone	2.05E-07	0.0E+00	1.43E-06	1.4E-05
Arsenic	2.35E-06	4.7E-06	1.65E-05	1.6E-02
Benzene	1.36E-06	4.0E-08	9.55E-06	0.0E+00
Benzo (a) anthracene	5.82E-07	6.7E-06	4.07E-06	0.0E+00
Benzo (a) pyrene	5.35E-07	6.1E-06	3.74E-06	0.0E+00
Benzo (b) fluoranthene	5.31E-07	6.1E-06	3.72E-06	0.0E+00
Benzo (k) fluoranthene	5.46E-07	6.3E-06	3.83E-06	0.0E+00
bis(2-ethylhexyl)phthalate	6.72E-06	9.4E-08	4.70E-05	0.0E+00
2-Butanone	3.99E-08	0.0E+00	2.79E-07	5.6E-06
Cadmium	5.70E-09	0.0E+00	3.99E-08	8.0E-05
Chromium	8.14E-07	0.0E+00	5.70E-06	5.7E-06
Chrysene	7.71E-07	8.9E-06	5.40E-06	0.0E+00
trans-1,2-Dichloroethylene	1.70E-07	0.0E+00	1.19E-06	5.9E-05
Dibenzo (a,h) anthracene				
Diethylphthalate	6.70E-07	0.0E+00	4.69E-06	5.9E-06
Ethylbenzene	1.88E-08	0.0E+00	1.32E-07	1.3E-06
Fluoranthene	1.15E-06	0.0E+00	8.02E-06	2.0E-04
Indeno (1,2,3-cd) pyrene	6.61E-08	7.6E-07	4.63E-07	0.0E+00
Lead	4.79E-07	0.0E+00	3.36E-06	2.3E-03
Mercury	4.36E-09	0.0E+00	3.05E-08	1.0E-04
Methylene Chloride	2.82E-07	2.1E-09	1.97E-06	3.3E-05
Pyrene	9.91E-07	0.0E+00	6.93E-06	2.3E-04
TOTALS		4.0E-05		2.0E-02

(a)Sample calculations and exposure parameters are given in Appendix G.

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(date:5/21/91)

(project:1490 6046)

TABLE 4.34

RISK CHARACTERIZATION
HYPOTHETICAL EXPOSURE SCENARIO: Sediment Ingestion at SW-16.

Groundwater/Surface Water Investigation Plan
Industri-Plex Superfund Site
Woburn, MA

Chemical	RISK CHARACTERIZATION FOR SEDIMENT EXPOSURE			
	CDI (Cancer)	CANCER RISK	CDI (Non-Cancer)	HAZARD INDEX
Acetone	2.22E-09		3.11E-08	3.11E-07
Arsenic	1.21E-05	2.4E-05	1.69E-04	1.69E-01
Benzo (a) anthracene	1.96E-07	2.3E-06	2.74E-06	0.00E+00
Benzo (a) pyrene	1.57E-07	1.8E-06	2.19E-06	0.00E+00
Benzo (b) fluoranthene	3.52E-07	4.1E-06	4.93E-06	0.00E+00
Benzo (k) fluoranthene	3.52E-07	4.1E-06	4.93E-06	0.00E+00
Beryllium	1.44E-08	6.2E-08	2.01E-07	4.02E-05
bis(2-ethylhexyl)phthalate	4.57E-08	6.4E-10	6.39E-07	3.20E-05
Cadmium	3.05E-07		4.27E-06	8.55E-03
Chromium	1.83E-06		2.56E-05	2.56E-05
Chrysene	1.70E-07	2.0E-06	2.37E-06	0.00E+00
Dibenzo (a,h) anthracene	4.04E-08	4.7E-07	5.66E-07	0.00E+00
Fluoranthene	2.87E-07		4.02E-06	1.00E-04
Indeno (1,2,3-cd) pyrene	7.57E-08	8.7E-07	1.06E-06	0.00E+00
Lead	4.62E-06		6.47E-05	4.53E-02
Mercury	5.22E-09		7.31E-08	2.44E-04
Pyrene	2.87E-07		4.02E-06	1.34E-04
	TOTAL	4.0E-05	TOTAL	2.2E-01

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TABLE 4.35

CUMULATIVE DAILY EXPOSURE (a)
HYPOTHETICAL EXPOSURE SCENARIO: Ingestion of Fish from Hall's Brook
(average ingestion rate)

Groundwater/Surface Water Investigation Plan
Industri-Plex Superfund Site
Woburn, MA

| Chemical | RISK CHARACTERIZATION FOR FISH INGESTION | | | |
	CDI (Cancer)	CANCER RISK	CDI (Non-Cancer)	HAZARD INDEX
Arsenic	5.11E-07	1.0E-06	1.85E-06	1.9E-03
bis(2-ethylhexyl)phthalate	1.11E-07	1.6E-09	4.04E-07	2.0E-05
Chromium	1.39E-06	0.0E+00	5.04E-06	5.0E-06
trans-1,2-Dichloroethene	1.73E-07	0.0E+00	6.27E-07	3.1E-05
Lead	6.10E-06	0.0E+00	2.21E-05	1.6E-02
Methylene Chloride	1.17E-06	8.8E-09	4.25E-06	7.1E-05
1,1,1-Trichloroethane	4.51E-07	0.0E+00	1.64E-06	1.8E-05
Trichloroethene	8.11E-07	8.9E-09	2.94E-06	0.0E+00
TOTAL		1.0E-06	TOTAL	1.8E-02

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(date:5/21/91)

(project:\490 5046)

TABLE 4.36

RISK CHARACTERIZATION
HYPOTHETICAL EXPOSURE SCENARIO: Ingestion of Fish from Hall's Brook
(for maximum fish ingestion rate)

Groundwater/Surface Water Investigation Plan
Industri-Plex Superfund Site
Woburn, MA

Chemical	RISK CHARACTERIZATION FOR FISH INGESTION EXPOSURE			
	CDI (Cancer)	CANCER RISK	CDI (Non-Cancer)	HAZARD INDEX
Arsenic	1.78E-06	3.6E-06	6.44E-06	6.4E-03
bis(2-ethylhexyl)phthalate	3.86E-07	5.4E-09	1.40E-06	7.0E-05
Chromium	4.82E-06	0.0E+00	1.75E-05	1.7E-05
trans-1,2-Dichloroethene	6.00E-07	0.0E+00	2.18E-06	1.1E-04
Lead	2.12E-05	0.0E+00	7.69E-05	5.4E-02
Methylene Chloride	4.07E-06	3.0E-08	1.48E-05	2.5E-04
1,1,1-Trichloroethane	1.56E-06	0.0E+00	5.68E-06	6.3E-05
Trichloroethene	2.88E-06	3.2E-08	1.04E-05	0.0E+00
	TOTAL	3.6E-06	TOTAL	6.1E-02

(file:\TBL4-36.WR1)

(date:5/21/91)

(project:\490 5046)

TABLE 4.37

CONTRIBUTION OF TRIBUTARIES TO TOTAL SURFACE WATER
DISCHARGE AT STATION SW-14

Groundwater/Surface Water Investigation Plan
Industri-Plex Superfund Site
Woburn, MA

INPUT LOCATION	PERCENT CONTRIBUTION [1]
Lower South Pond	
North Fork of Aberjona River	6.2
South Fork of Aberjona River (Phillip's Pond)	5.7
Hall's Brook	14.2
Hall's Brook Holding Area (2)	43.5
Unknown Sources	27.3
TOTAL	3.0
	100.0

[1] Based on the average of two surface water measurement periods
(August and September, 1990).

2

This was estimated by subtracting measured discharge from SW-10
and SW-12 from the total discharge at SW-14. It is assumed to
be contributed by groundwater flux into the HBRA.

FILE:TBL4-37.WR1

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TABLE 4.38

WATER QUALITY PARAMETERS MEASURED AT
SELECTED STATIONS DURING THE FIELD SURVEY

Groundwater/Surface Water Investigation Plan
Industri-Plex Superfund Site
Woburn, MA

STATION NUMBER	pH	D.O. (ppm)	Temperature (C)	Conductivity (umhos)
BS-1A	7.1	14.0	10.8	230
BS-1B	7.0	12.4	11.1	280
BS-1C	6.9	10.4	11.2	31
BS-2A	6.8	10.3	14.5	33
BS-2B	6.7	4.1	13.0	82
BS-2C	6.7	10.4	15.5	33
BS-3	6.0	6.4	15.0	100
BS-4	6.7	10.8	8.8	410
BS-5	6.8	8.3	18.5	323
BS-6	6.7	6.1	14.5	990
BS-7	6.6	9.8	16.5	1060
BS-8	6.9	8.1	12.2	310
BS-9	6.9	7.5	16.5	500
BS-10	6.8	8.2	13.8	330
BS-11	6.8	7.2	16.5	480
BS-12	6.9	7.4	17.0	315
BS-13	6.9	6.8	16.5	480
BS-14	6.9	5.8	14.0	312
BS-15	6.8	8.6	10.0	900
BS-16	7.1	2.1	12.5	162
BS-17	6.8	9.5	11.5	430
BS-18	7.0	8.8	13.0	38
BS-19	6.7	8.9	15.0	340
BS-20	6.3	7.4	14.5	250
BS-21	6.8	9.2	15.5	380
BS-22	7.3	17.1	10.3	200
BS-23	7.0	12.2	9.5	177
BS-24	6.9	7.1	14.2	360
BS-25	6.8	7.4	14.0	380
BS-26	7.0	8.1	12.2	290

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TABLE 4.39

NUMBER AND TYPES OF FISH SAMPLED
AT SELECTED BIOLOGICAL SAMPLING STATIONS

Groundwater/Surface Water Investigation Plan
Industri-Plex Superfund Site
Woburn, MA

Station #	Common Name	Scientific Name	# Sampled
BS-11	Golden Shiner	Notemigonus crysoleucas	1
BS-14	White Sucker	Catostomus commersoni	1
	American Eel	Anguilla rostrata	1
	Largemouth Bass	Micropterus salmoides	1
	Pumpkinseed	Lepomis gibbosus	2
BS-26	Golden Shiner	Catostomus commersoni	4
	White Sucker	Notemigonus crysoleucas	3
	Largemouth Bass	Micropterus salmoides	1
South pond	pumpkinseed	Lepomis gibbosus	13
BS-1a,b,c	golden shiner	Notemigonus crysoleucas	1

Note: Pumpkinseeds were observed during surface water flow

studies at SW-5, -10, and -13. American Eel were caught at

SW-5 and SW-12, but not collected. Largemouth bass were

reported to have been caught in the HBRA by local fishermen.

TABLE 4.40
COMPOSITE LIST OF WILDLIFE SPECIES OBSERVED ON-SITE
Groundwater/Surface Water Investigation Plan
Industri-plex Superfund Site
Woburn, MA

		Observed By:		
Common Name	Scientific Name	WMS, Inc.	Normandeau Inc.	ES&E Inc.
BIRDS				
American crow	Corvus brachyrhynchos	X	X	X
American goldfinch	Carduelis tristis		X	
American kestrel	Falco sparverius		X	X
American robin	Turdus migratorius		X	X
Barred owl	Strix varia		X	
Belted kingfisher	Ceryle alcyon		X	X
Black duck	Ana rubripes		X	
Black-capped chickadee	Parus atricapillus		X	X
Blue jay	Cyanocitta cristata		X	X
Brown thrasher	Toxostoma rufum		X	
Canada geese	Branta canadensis	X	X	X
Common grackle	Quiscalus quiscula		X	X
Common snipe	Gallinago gallinago		X	X
Downy woodpecker	Picoides pubescens		X	X
European starling	Sturnus vulgaris		X	X
Great blue heron	Ardea herodias		X	X
Green-backed heron	Butorides striatus		X	X
Green-winged teal	Anas crecca		X	
Hairy woodpecker	Picoides villosus		X	
Herring gull	Larus argentatus		X	X
Killdeer	Charadrius vociferus	X	X	
Mallard	Anas platyrhynchos	X	X	X
Mourning dove	Zenaidura macroura	X	X	
Northern flicker	Colaptes auratus	X	X	
Northern mockingbird	Mimus polyglottos		X	X
Pine warbler	Dendroica pinus		X	
Red-tailed hawk	Buteo lineatus		X	X
Red-winged blackbird	Agelaius phoeniceus	X	X	X
Ring-necked pheasant	Phasianus colchicus	X	X	X
Ruffed grouse	Bonasa umbellus		X	
Song sparrow	Melospiza melodia	X	X	X
Wood thrush	Hylocichla mustelina		X	X
Wren (unidentified)	--		X	
Yellow warbler	Dendroica petechia	X		X

TABLE 4.40
COMPOSITE LIST OF WILDLIFE SPECIES OBSERVED ON-SITE
Groundwater/Surface Water Investigation Plan
Industri-plex Superfund Site
Woburn, MA

Common Name	Scientific Name	WMS, Inc.	Normandeau Inc.	ES&E Inc.
MAMMALS				
Cottontail (unidentified)	Sylvilagus spp.		X	X
Domestic cat	Felis catus		X	
Eastern cottontail	Sylvilagus floridanus	X		
Gray squirrel	Sciurus carolinensis		X	X
Mole (unidentified)	--		X	X
Muskrat	Ondatra zibethicus		X	X
Raccoon	Procyon lotor	X	X	X
River otter	Lutra canadensis		X	X
White-tailed deer	Odocoileus virginianus	X		
Woodchuck	Marmota monax		X	X
AMPHIBIANS				
Gray treefrog	Hyla versicolor		X	
Green frog	Rana clamitans melanota		X	X
Northern leopard frog	Rana pipiens	X		X
Northern spring peeper	Hyla c. crucifer		X	
Tadpoles (unidentified)	--		X	X
REPTILES				
Common snapping turtle	Chelydra s. serpentina		X	X
Eastern painted turtle	Chrysemys picta	X	X	X
Garter snake	Thamnophis sirtalis		X	X
FISH				
Pumpkinseed	Lepomis gibbosus	X		X
Golden Shiner	Notemigonus crysoleucas			X
White Sucker	Catostomus commersoni			X
American Eel	Anguilla rostrata			X
Largemouth Bass	Micropterus salmoides			X
SHELLFISH				
Crayfish	Orconectes sp.	X		X

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TABLE 4.41

RELATIVE PERCENT CONTRIBUTION OF BENTHIC MACROINVERTEBRATES
AT EACH SAMPLING STATION

Groundwater/Surface Water Investigation Plan
Industri-Plex Superfund Site
Woburn, MA

LOTIC HABITAT	% Ephemer-optera	% Plec-optera	% Trich-optera	% Odonata	% Hemi-ptera	% Cole-ptera	% Diptera: (misc.)	% Diptera: Chiron.	% Crust-acea	% Mollusca	% Oligo-chata	% Other
Aberjona River												
BS-20 (reference)	0	0	0	0	0	0	1	19	0	1	79	0
BS-21 (reference)	0	0	0	0	0	1	2	49	8	0	39	1
BS-3 (reference)	0	0	4	2	2	22	13	0	55	0	0	4
BS-4 (reference)	3	3	6	0	0	6	9	18	56	0	0	0
BS-17	0	0	0	0	0	0	71	29	0	0	0	0
BS-2	0	0	0	0	0	1	62	8	6	2	21	0
BS-5	0	0	0	0	0	3	5	60	3	1	28	0
BS-12	0	0	0	0	0	1	27	66	6	0	1	0
BS-14A	0	0	45	0	0	0	12	37	1	0	4	1
BS-14B	0	0	0	0	0	0	8	65	2	0	24	0
New Boston St. Drainage												
BS-18 (reference)	0	0	2	0	0	0	2	5	5	0	85	0
BS-19 (reference)	0	0	0	1	0	1	1	7	9	1	78	3
BS-6	0	0	0	0	0	4	0	78	1	0	17	0
BS-7	0	0	0	12	0	0	0	0	88	0	0	0
BS-10	0	0	36	4	4	4	0	50	0	0	4	0
BS-15	0	0	0	0	0	0	0	10	3	0	86	0
LENTIC HABITAT												
Hide Pile Wetland												
BS-22 (reference)	0	0	0	0	0	0	0	39	0	1	61	0
BS-23 (reference)	0	0	0	0	0	0	0	19	0	0	24	57
BS-1A	0	0	0	7	0	0	0	93	0	0	0	0
BS-1B	0	0	0	0	0	0	0	91	0	0	9	0
BS-1C	0	0	0	0	0	0	2	94	0	0	5	0
Hall's Brook Retention Area												
BS-9	0	0	0	0	0	0	0	0	100	0	0	0
BS-11	0	0	0	0	0	0	0	0	0	0	0	0
BS-13	0	0	0	0	0	0	0	6	0	0	94	0
BS-16	0	0	1	0	0	2	0	97	0	0	0	0
Phillip's Pond												
BS-8 (reference)	0	0	0	0	0	0	0	2	0	0	98	0
BS-26 (reference)	0	0	0	0	0	0	0	9	0	0	91	0
Pond near Trailer												
BS-24 (reference)	0	0	0	0	0	0	3	9	39	0	48	0
BS-25 (reference)	0	0	0	0	0	0	0	95	5	0	0	0

Includes organisms identified as pupae.

TABLE 4.42

TOXICITY QUOTIENTS FOR METALS IN SURFACE WATER
(based on Ambient Water Quality Criteria)

Groundwater/Surface Water Investigation Plan
Industri-Plex Superfund Site
Woburn, MA

TOTAL METALS	SW-1	SW-2	SW-4	SW-5	SW-6	SW-7	SW-8	SW-9	SW-10	SW-11	SW-12	SW-13	SW-14	SW-15	SW-17
Arsenic	0.00	0.21	0.00	0.08	0.09	0.00	0.01	0.04	0.04	0.05	0.00	0.00	0.07	0.08	0.16
Barium	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Chromium	0.00	0.00	0.00	0.00	0.00	0.03	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.01	0.00
Copper	0.00	0.00	0.00	0.00	0.00	0.00	0.62	0.75	0.59	0.46	0.00	0.50	0.58	0.40	0.00
Lead	0.03	0.03	0.05	0.03	0.01	0.00	0.08	0.04	0.08	0.04	0.04	0.06	0.07	0.00	0.05
Manganese (2)	0.06	0.57	0.10	0.13	0.77	0.89	0.06	0.36	0.56	0.31	0.13	0.30	0.55	1.23	0.19
Zinc	0.07	0.06	0.05	0.10	0.03	0.00	0.09	0.85	0.00	0.45	0.15	0.50	0.51	0.00	0.06
TOTAL UNITS =	0.16	0.88	0.19	0.35	0.91	0.92	0.86	2.05	1.29	1.30	0.33	1.37	1.78	1.72	0.46

DISSOLVED METALS	SW-1	SW-2	SW-4	SW-5	SW-6	SW-7	SW-8	SW-9	SW-10	SW-11	SW-12	SW-13	SW-14	SW-15	SW-17
Arsenic	0.00	0.13	0.00	0.07	0.06	0.01	0.00	0.04	0.02	0.03	0.06	0.03	0.04	0.03	0.09
Barium	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Copper	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Manganese (2)	0.04	0.62	0.07	0.13	1.91	0.88	0.03	0.37	0.54	0.55	0.14	0.54	0.75	1.23	0.19
Zinc	0.00	0.00	0.00	0.15	0.07	0.09	0.04	0.81	0.14	0.38	0.20	0.36	0.32	0.05	0.10
TOTAL UNITS =	0.04	0.75	0.07	0.35	2.04	0.98	0.07	1.22	0.70	0.96	0.40	0.93	1.11	1.31	0.38

[1]
The measured concentrations of total and dissolved metals were divided by each respective ambient water quality criterion (cited below) to gain perspective on the relative impact of each metal, and of the mixture as a whole. The summed ratios for each station ("total units") is an exercise designed to inform the reader as to the relative rank of each station, i.e. the potential impact as a mixture. It does not convey additivity, or the exceedance of Ambient Water Quality Criteria at levels greater than unity.

[2]
No criteria is available for manganese. The lower tolerance value for toxicity to freshwater aquatic organisms was used as a conservative benchmark.

The following equations were used to calculate AWQC (metal concentration is in ppb, hardness in ppm):

$[arsenic]/190$

$[barium]/50000$

$[chromium]/e^{(0.819 \cdot LN([hardness]) + 3.688)}$

$[copper]/e^{(0.9422 \cdot LN([hardness]) - 1.464)}$

$[lead]/e^{(0.76 \cdot LN([hardness]) + 1.06)}$

$[manganese]/1500$

$[zinc]/e^{(0.83 \cdot LN([hardness]) + 1.95)}$

TABLE 4.43

TOXICITY QUOTIENTS FOR METALS IN SEDIMENT

Groundwater/Surface Water Investigation Plan
Industri-Plex Superfund Site
Woburn, MA

	ER-L	SW-1	SW-2	SW-3	SW-4	SW-5	SW-6	SW-7	SW-8	SW-9	SW-10	SW-11	SW-12	SW-13	SW-14	SW-15	SW-16	SW-17
Antimony	2	3.7	0.0	0.0	0.0	0.0	0.0	187.5	1.6	20.8	8.2	0.0	0.0	0.0	0.0	9.9	0.0	0.0
Arsenic	33	0.1	11.2	0.9	0.1	0.4	4.7	47.9	0.1	297.9	5.2	53.0	0.3	40.3	0.6	15.5	28.1	1.8
Cadmium	5	0.0	0.2	0.0	0.6	0.5	0.7	0.0	0.0	10.3	0.4	5.5	0.4	2.8	0.0	0.5	4.7	0.7
Chromium	80	0.4	6.8	0.4	0.3	0.3	1.2	4.1	0.1	13.6	0.4	6.6	0.2	4.8	0.2	1.5	1.8	1.3
Copper	70	0.5	1.7	0.6	0.5	0.2	0.3	3.1	0.2	16.6	1.1	7.5	0.4	4.1	0.2	2.4	5.1	1.0
Lead	35	0.3	6.1	0.8	0.8	0.8	0.8	120.3	0.2	17.5	9.0	9.1	1.2	7.9	0.2	9.9	10.1	3.3
Zinc	120	0.5	1.6	0.6	0.4	0.7	0.4	3.2	0.1	66.2	1.9	49.8	0.4	21.5	0.6	3.6	13.3	1.3
	ER-M																	
Antimony	25	0.3	0.0	0.0	0.0	0.0	0.0	15.0	0.1	1.7	0.7	0.0	0.0	0.0	0.0	0.8	0.0	0.0
Arsenic	65	0.1	4.4	0.3	0.0	0.1	1.8	18.6	0.0	115.6	2.0	20.6	0.1	15.6	0.2	6.0	10.9	0.7
Cadmium	9	0.0	0.1	0.0	0.3	0.3	0.4	0.0	0.0	5.7	0.2	3.0	0.2	1.6	0.0	0.3	2.6	0.4
Chromium	145	0.2	3.8	0.2	0.2	0.2	0.7	2.3	0.0	7.5	0.2	3.6	0.1	2.6	0.1	0.8	1.0	0.7
Copper	390	0.1	0.3	0.1	0.1	0.0	0.0	0.6	0.0	3.0	0.2	1.3	0.1	0.7	0.0	0.4	0.9	0.2
Lead	110	0.1	1.9	0.2	0.3	0.3	0.2	38.3	0.1	5.6	2.9	2.9	0.4	2.5	0.1	3.1	3.2	1.1
Zinc	270	0.2	0.7	0.3	0.2	0.3	0.2	1.4	0.1	29.4	0.8	22.1	0.2	9.6	0.3	1.6	5.9	0.6

1

Sediment criteria are not currently available for determining impacts of metals to aquatic receptors.
However, NOAA has reviewed and compiled studies relating sediment concentrations of metals to effects on the
benthic community. These studies have been ranked according to the effective concentration of each compound
In sediment. The ER-L, or "Effects Range – Low" is the concentration that falls into the 10th percentile for
all of the studies listed, while the ER-M, or "Effects Range – Median", falls near the 50th percentile. The
sediment concentration of each constituent was then divided by these "ER" values to generate a "hazard quotient".
Although value greater than 1.0 indicates the ER value has been exceeded, it is not indicative that an adverse
effect will occur.

TBL4-43.WR1

TABLE 4.44

[1]

TOXICITY QUOTIENTS FOR POLYCYCLIC AROMATIC HYDROCARBONS
IN SEDIMENT

Groundwater/Surface Water Investigation Plan
Industri-Plex Superfund Site
Woburn, MA

		SW-1	SW-2	SW-3	SW-4	SW-5	SW-6	SW-7	SW-8	SW-9	SW-10	SW-11	SW-12	SW-13	SW-14	SW-15	SW-16	SW-17
PERCENT TOTAL ORGANIC CARBON	ER-L	0.84	0.47	0.91	—	—	14.6	1.2	0.27	20.2	0.23	15.8	—	9.9	0.17	0.65	23	—
Anthracene	85	0.0	3.8	0.0	0.0	2.4	0.0	0.0	0.0	0.0	0.0	17.6	34.1	0.0	0.0	9.1	20.0	0.0
Benzo (a) anthracene	230	0.0	3.8	0.0	0.0	3.3	0.0	3.7	0.0	0.0	0.0	12.6	47.8	5.2	2.1	5.2	65.2	0.0
Benzo (a) pyrene	400	0.0	1.5	0.0	0.0	1.9	0.0	1.6	0.0	0.0	0.0	6.8	24.8	2.5	1.0	2.2	30.0	0.0
Chrysene	400	0.0	2.2	0.0	0.0	2.8	0.0	2.2	0.0	0.0	0.0	11.3	32.5	2.5	1.0	2.2	30.0	0.0
Dibenzo (a,h) anthracene	60	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	43.3	0.0	0.0	2.0	51.7	0.0
Fluoranthene	600	0.0	2.5	0.0	0.0	2.7	2.0	2.7	0.0	0.0	0.0	13.8	40.0	5.3	2.2	4.7	36.7	0.2
Fluorene	35	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	6.9	0.0	0.0
Phenanthrene	225	0.0	4.4	0.0	0.0	4.0	4.4	2.6	0.0	0.0	0.0	31.6	75.6	12.4	1.6	14.2	44.0	0.0
Pyrene	350	0.0	4.3	0.0	0.0	4.3	3.4	3.7	0.0	0.0	0.0	18.9	62.9	7.4	3.1	6.6	62.9	0.3
Total PAH	4000	0.0	2.4	0.0	0.0	2.8	0.9	2.1	0.0	0.0	0.0	10.6	38.2	3.7	1.4	4.2	41.1	0.1
	ER-M																	
Anthracene	960	0.0	0.3	0.0	0.0	0.2	0.0	0.0	0.0	0.0	0.0	1.6	3.0	0.0	0.0	0.8	1.8	0.0
Benzo (a) anthracene	1600	0.0	0.5	0.0	0.0	0.5	0.0	0.5	0.0	0.0	0.0	1.8	6.9	0.8	0.3	0.8	9.4	0.0
Benzo (a) pyrene	2500	0.0	0.2	0.0	0.0	0.3	0.0	0.3	0.0	0.0	0.0	1.1	4.0	0.4	0.2	0.8	4.8	0.0
Chrysene	2800	0.0	0.3	0.0	0.0	0.4	0.0	0.3	0.0	0.0	0.0	1.6	4.6	0.6	0.2	0.3	4.6	0.0
Dibenzo (a,h) anthracene	260	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	10.0	0.0	0.0	0.5	11.9	0.0
Fluoranthene	3600	0.0	0.4	0.0	0.0	0.4	0.3	0.4	0.0	0.0	0.0	2.3	6.7	0.9	0.4	0.8	6.1	0.0
Fluorene	640	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.4	0.0	0.0
Phenanthrene	1380	0.0	0.7	0.0	0.0	0.7	0.7	0.4	0.0	0.0	0.0	5.1	12.3	2.0	0.3	2.3	7.2	0.0
Pyrene	2200	0.0	0.7	0.0	0.0	0.7	0.5	0.6	0.0	0.0	0.0	3.0	10.0	1.2	0.5	1.0	10.0	0.0
Total PAH	35000	0.0	0.3	0.0	0.0	0.3	0.1	0.2	0.0	0.0	0.0	1.2	4.4	0.4	0.2	0.5	4.7	0.0

[1]
Sediment criteria are not currently available for determining impacts of PAH compounds to aquatic receptors.
However, NOAA has reviewed and compiled studies relating sediment concentrations of PAH's to effects on the
benthic community. These studies have been ranked according to the effective concentration of each compound
in sediment. The ER-L, or "Effects Range – Low" is the concentration that falls into the 10th percentile for
all of the studies listed, while the ER-M, or "Effects Range – Median", falls near the 50th percentile. The
sediment concentration of each constituent was then divided by these "ER" values to generate a "hazard quotient".
Although value greater than 1.0 indicates the ER value has been exceeded, it is not indicative that an adverse
effect will occur.

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TABLE 4.45

CONTRIBUTION OF CONSTITUENTS OF CONCERN FROM GROUNDWATER
TO SURFACE WATER FOR THE HALL'S BROOK RETENTION AREA
AND A PORTION OF THE ABERJONA RIVER
(Worst-case Future Scenario)

Groundwater/Surface Water Investigation Plan
Industri-Plex Superfund Site
Woburn, MA

5 CONSTITUENT OF CONCERN	1 Current Groundwater Concentration (ug/l)		2 Current In-Stream Concentration (ug/l)		3 Future In-Stream Concentration (ug/l)		4 TOXICITY QUOTIENT	
	HBRA	Aberjona R.	HBRA	Aberjona R.	HBRA	Aberjona R.	HBRA	Aberjona R.
Arsenic	25	49	6	18	25	49	0.13	0.26
Copper	6	3	3	2	6	3	0.33	0.16
Zinc	79	7	147	37	79	7	0.36	0.03
Benzene	31	56	3	3	3	56	0.01	0.14
Toluene	6	1,050	3	3	1	1,050	0.00	0.60
Phenol	5	25	5	5	1	25	0.00	0.01

1

Calculated as the geometric mean of OW-12,-13,-17, and -18 for the HBRA and OW-16 and OW-28 for the Aberjona River.
2

Calculated as the geometric mean of SW-09,-11, and -13 for the HBRA. Concentration at SW-17 was used for the Aberjona River.
3

See Section 4.4.10.3 of text for a discussion of how these concentrations were estimated.
4

Toxicity quotient is the future in-stream concentration divided by the respective AWQC. Criteria for metals are given in Table
4.42. Criteria use for benzene, toluene, and phenol were 400, 1750, and 2650, respectively. The value for phenol was estimated
by assuming an acute/chronic ratio of ten, and dividing the acute value by this amount. 94.1 mg/l was used for a hardness value.
5

Dissolved concentrations were used for metals.
6

A value of one-half the detection limit was used if the compound went undetected.

TABLE 4.46

MEASUREMENT ENDPOINTS AND BIOASSESSMENT CRITERIA FOR
EACH BIOLOGICAL SAMPLING STATION

Groundwater/Surface Water Investigation Plan
Industrl-Plex Superfund Site
Woburn, MA

SAMPLING STATION	RBP II Habitat Score	Taxa Richness	Total Abundance	Family Biotic Index (modified)	Shannon-Weaver Diversity Index	Evenness	EPT Index	EPT/ Chironomidae Ratio
Aberjona River								
BS-20 (reference)	84	9	401	9.2	0.63	0.29	0	0.00
BS-21 (reference)	56	8	370	7.7	1.10	0.53	1	0.01
BS-3 (reference)	53	12	55	5.6	1.88	0.76	2	0.00
BS-4 (reference)	83	10	34	6.8	1.58	0.69	4	0.67
BS-2	34	10	1643	7.0	1.13	0.49	0	0.00
BS-17	31	2	7	6.0	0.60	0.86	0	0.00
BS-5	38	12	401	7.2	1.13	0.45	1	0.00
BS-12	67	7	236	6.1	0.92	0.47	0	0.00
BS-14A	101	7	83	7.0	1.29	0.66	1	1.19
BS-14B	48	5	121	5.3	0.96	0.60	0	0.00
New Boston St. Drainage								
BS-18 (reference)	75	11	559	9.4	0.66	0.27	1	0.32
BS-19 (reference)	63	19	1015	9.3	1.00	0.34	2	0.07
BS-6	42	5	341	6.7	0.68	0.42	0	0.00
BS-7	25	3	17	4.0	0.44	0.40	0	0.00
BS-15	39	3	29	9.6	0.48	0.44	0	0.00
BS-10	88	6	28	5.4	1.19	0.66	1	0.71

* Includes organisms identified as pupae. All stations are listed in order of north to south (upstream to downstream).

TBL4-46.WR1

TABLE 4.47

BIOLOGICAL CONDITION OF SAMPLING STATION   1
BASED ON RAPID BIOASSESSMENT PROTOCOL II SCORING CRITERIA

Groundwater/Surface Water Investigation Plan
Industri-Plex Superfund Site
Woburn, MA

SAMPLING STATION [2,3]	TAXA RICHNESS	FAMILY BIOTIC INDEX (modified)	EPT INDEX	RATIO OF EPT TO CHIRONOMIDAE	PERCENT CONTRIBUTION OF DOMINANT FAMILY	COMMUNITY LOSS INDEX	TOTAL BIOASSESSMENT SCORE	PERCENT OF REFERENCE SCORE	DEGREE OF IMPAIRMENT
ABERJONA RIVER									
REFERENCE [N = 4]	6	8	6	6	0	6	30.0		
BS-2	6	6	0	0	0	6	18.0	60	MODERATE
BS-17	0	6	0	0	0	3	9.0	30	MODERATE
BS-5	6	6	0	0	0	6	18.0	60	MODERATE
BS-12	3	6	0	0	0	3	12.0	40	MODERATE
BS-14B	3	6	0	0	0	3	12.0	40	MODERATE
BS-14A	3	6	0	6	3	3	21.0	70	MODERATE
NEW BOSTON ST. DRAINAGE									
REFERENCE [N = 2]	6	8	6	6	0	6	30.0		
BS-6	0	6	0	0	0	3	9.0	30	MODERATE
BS-7	0	6	0	0	0	0	6.0	20	SEVERE
BS-15	0	6	0	0	0	0	6.0	20	SEVERE
BS-10	3	6	0	6	3	3	21.0	70	MODERATE

1
As documented in EPA, 1989f.

2
Biological sampling stations are generally listed from upstream to downstream locations.

3
REFERERENCE = Reference stations with similar habitat types, located upstream of each station within that drainage area.
Because several reference stations were sampled and the variability between each station was low, it was decided that, for the
purposes of the RBP, the functional parameters could be safely averaged. Each sampling station was then compared to the mean
reference value. The following served as reference stations for the respective drainage area: Aberjona River, BS-20,-21,-3, and -4;
Hall's Brook Drainage, BS-18 and -19.

TABLE 4.48

IDENTIFICATION OF CHIRONOMIDAE AT SELECTED
UPSTREAM AND DOWNSTREAM SAMPLING STATIONS

Groundwater/Surface Water Investigation Plan
Industri-Plex Superfund Site
Woburn, MA

Taxonomic Group	BS-4	BS-18	BS-19	BS-21	BS-1C	BS-10	BS-14B	BS-14A
CHIRONOMINAE								
Chironomini					3/ 4.9%			
Chironomus		1/ 4.2%	6/ 7.9%		58/ 95.1%			
Dicrotendipes nervosus							2/ 2.9%	
Parachironomus abortivus			2/ 2.6%					
Paratendipes albimanus			2/ 2.6%					
Polypedilum illinoense		1/ 4.2%	6/ 7.9%	1/ 1.0%			2/ 2.9%	3/ 10.3%
Tanylarsus sp.				130/ 75.6%				1/ 3.4%
DIAMESINAE								
Diamesa sp.				4/ 2.3%				
ORTHOCLADIINAE								
Brillia flavifrons		14/ 58.3%		1/ 1.0%				
Cricotopus bicinctus	1/ 25.0%	3/ 12.5%	42/ 60.5%	25/ 14.5%		13/ 92.9%	60/ 88.2%	16/ 55.2%
Cricotopus sylvestris gr.		1/ 4.2%	2/ 2.6%	1/ 1.0%			2/ 2.9%	1/ 3.4%
Cricotopus tremulus gr.	1/ 25.0%		4/ 5.3%	1/ 1.0%			2/ 2.9%	5/ 17.2%
Cricotopus/Orthocladius sp.								1/ 3.4%
Eukiefferiella claripennis gr.	2/ 50.0%		2/ 2.6%	9/ 5.2%		1/ 7.1%		
Psectrocladius psilopterus gr.			4/ 5.3%					
TANYPODINAE								
Thlenemannimyia gr.		4/ 16.7%	2/ 2.6%					2/ 6.9%
TOTAL NUMBER LARVAE:	4	24	72	172	61	14	68	29
TOTAL NUMBER TAXA:	3	6	10	8	2	2	5	7

Table #: Chironomid larvae taxa found at each of eight BS-1C to BS-21. The first number in each column is the specimen count:
the second number is the percentage of the total chironomid larval community at each station represented by each taxon.

File: TBL4-48.WR1

EPA Region I New England
Superfund Document Management System

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Page # _____

Imagery Cover Sheet
Unscannable Item

Contact the Superfund Records Center to View this Document

Site Name ___Industri Plex_____

Operable Unit _____

Break Number ___3. 6_____

Report or Document Title ___Ground-Water/Surface Water_____

Investigation Plan, Phase 1 Remedial Investigation (Vol. 1 of 5)

Date of Item ___June 7, 1991_____

Description of Item ___dBase III+ Analytical Data Files_____

Number and Type of Item(s) ___2 3½ inch diskettes_____

STUDY AREA

LOCATION OF SITE

N

LOCATION OF SITE AND STUDY AREA

Title			
Prepared for			
INDUSTRI-PLEX SITE REMEDIAL TRUST			

ROUX	Compiled by JG	Date 1/91	Figure
ROUX ASSOCIATES INC	Prepared by SW	Scale 1" = 2000'	1
Consulting Ground Water	Project Mgr WS	Revision 0	
Geologists & Engineers	File No 06609		
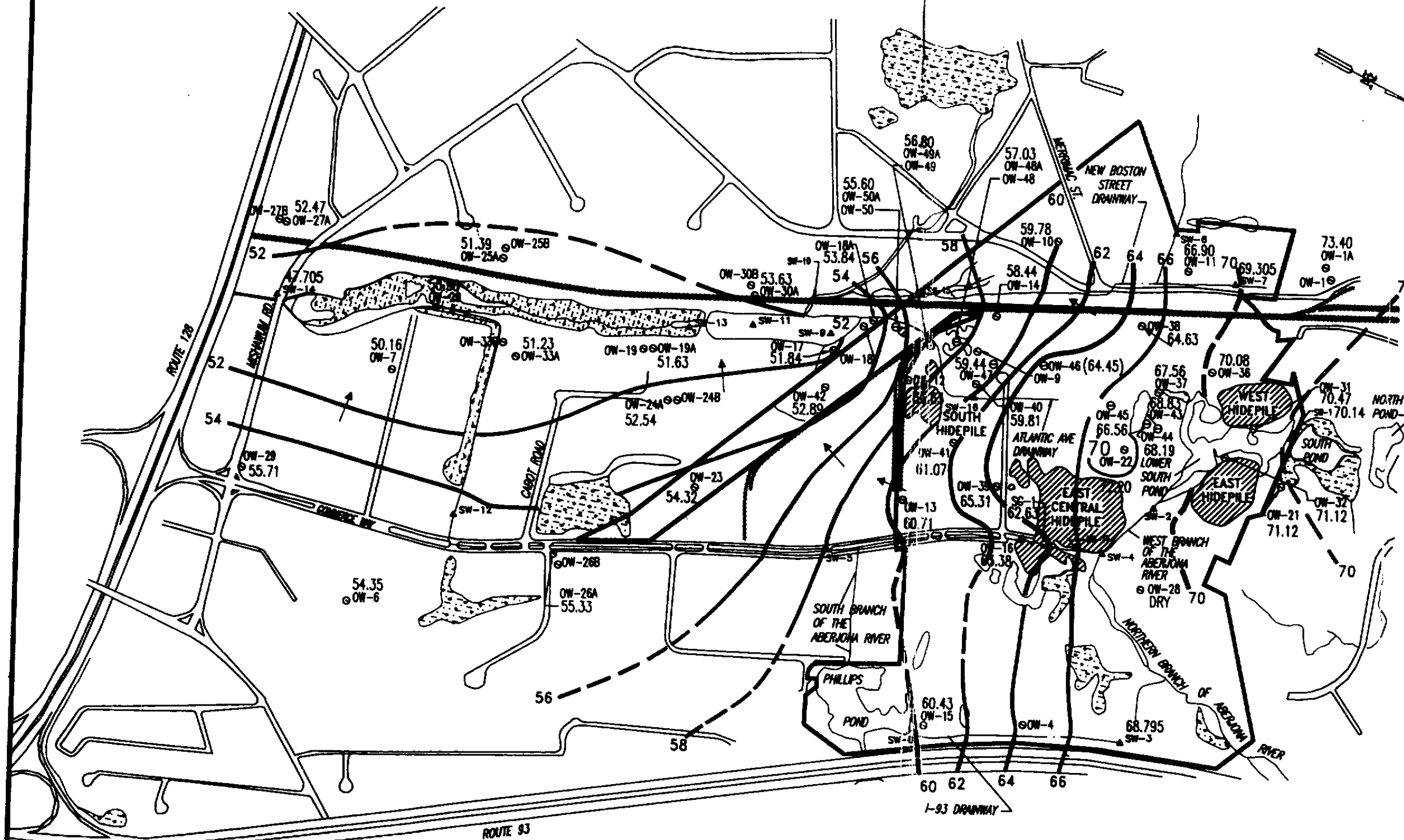
EXPLANATION

OW-21 ⊙ OBSERVATION WELL LOCATION AND DESIGNATION.

71.12 ELEVATION OF WATER TABLE IN FEET ABOVE MEAN SEA LEVEL.

▲SW-7 SURFACE-WATER SAMPLING STATION LOCATION AND DESIGNATION.

SG-1 ○ ABERJONA RIVER STAGE GAUGE LOCATION AND DESIGNATION.

60━━ LINE OF EQUAL ELEVATION OF THE WATER TABLE IN FEET ABOVE MEAN SEA LEVEL, DASHED WHERE INFERRED.

◄━ GROUND-WATER FLOW DIRECTION.

WETLANDS AREAS

TITLE:

ELEVATION OF
THE WATER TABLE
MAY 13, 1991

PREPARED FOR:

INDUSTRI-PLEX REMEDIAL TRUST

ROUX
ROUX ASSOCIATES, INC.
ENVIRONMENTAL CONSULTING
& MANAGEMENT

COMPILED BY:	J.Y.	DATE:	05/91	FIGURE
PREPARED BY:	R.P./C.L.	SCALE:	AS SHOWN	
PROJECT MANAGER:	T.B.	REVISION:	0	2
PROJECT NO.		066090		

0'   800'   1600'

WEST

EAST

HALLS BROOK

WATER TABLE

FILL

K_4

FINE TO MEDIUM SANDS
(GLACIAL LAKE/POND DEPOSITS)

TILL

CRYSTALLINE
BEDROCK

FINE TO COARSE SANDS
(GLACIAL OUTWASH DEPOSITS)

K_3

CRYSTALLINE
BEDROCK

K_2

SAND (GLACIAL STREAM/LAKE DEPOSITS)
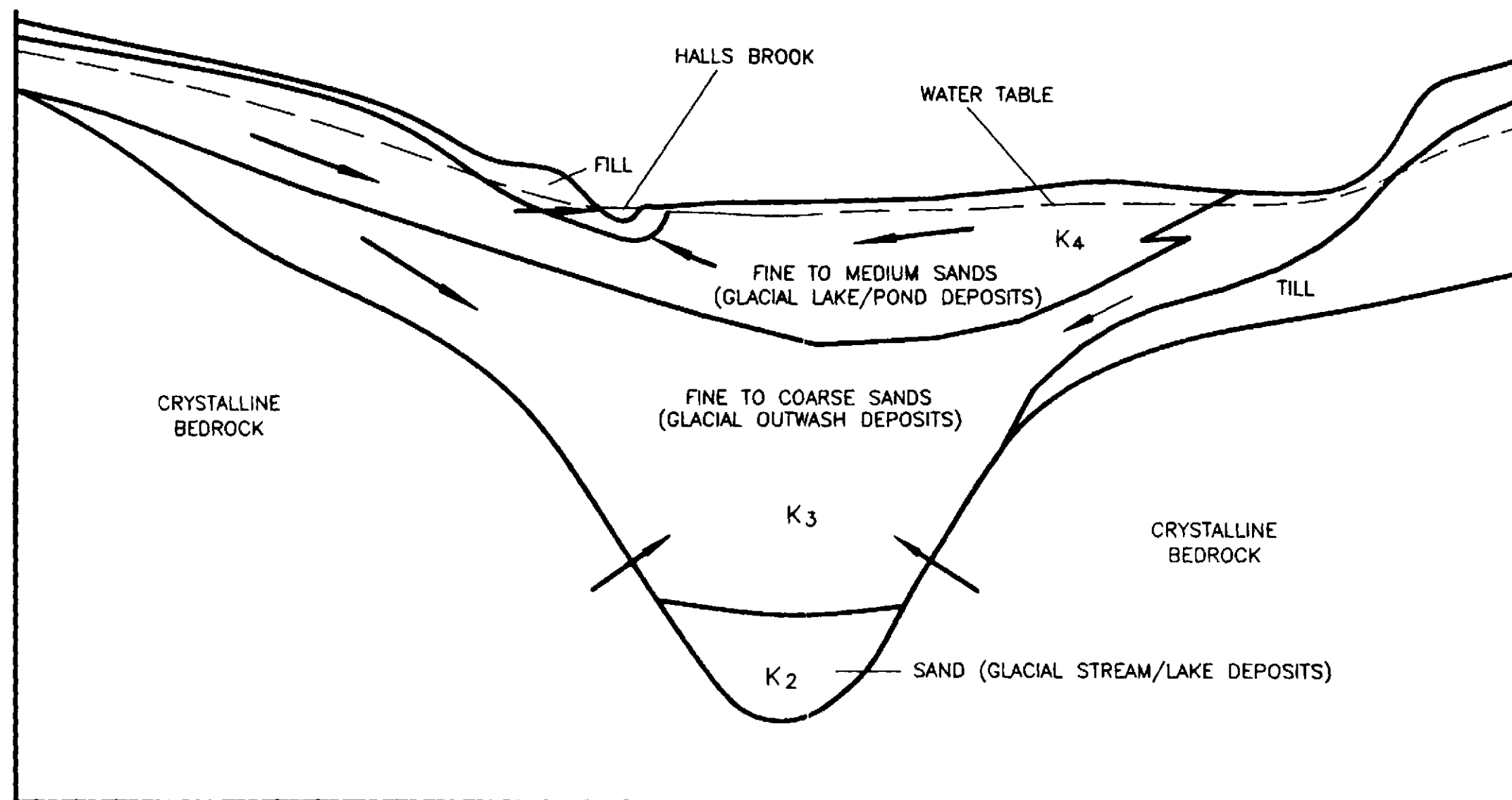
EXPLANATION

APPROXIMATE DIRECTION OF GROUND-WATER FLOW

K_2 HYDRAULIC CONDUCTIVITY OF UNIT

$K_4 < K_3 < K_2$ RELATIVE HYDRAULIC CONDUCTIVITIES

NOT TO SCALE

Title:

**CONCEPTUAL MODEL
OF THE GROUND-WATER
FLOW SYSTEM,
INDUSTRI-PLEX SITE,
WOBURN, MASSACHUSETTS**

Prepared for:

INDUSTRI-PLEX SITE REMEDIAL TRUST

ROUX	Compiled by: W.S.	Date: 1/91	Figure
ROUX ASSOCIATES INC	Prepared by: S.W.	Scale: NONE	
Consulting Ground-Water	Project Mgr: W.S.	Revision: 0	**3**
Geologists & Engineers	File No: 06609Y		
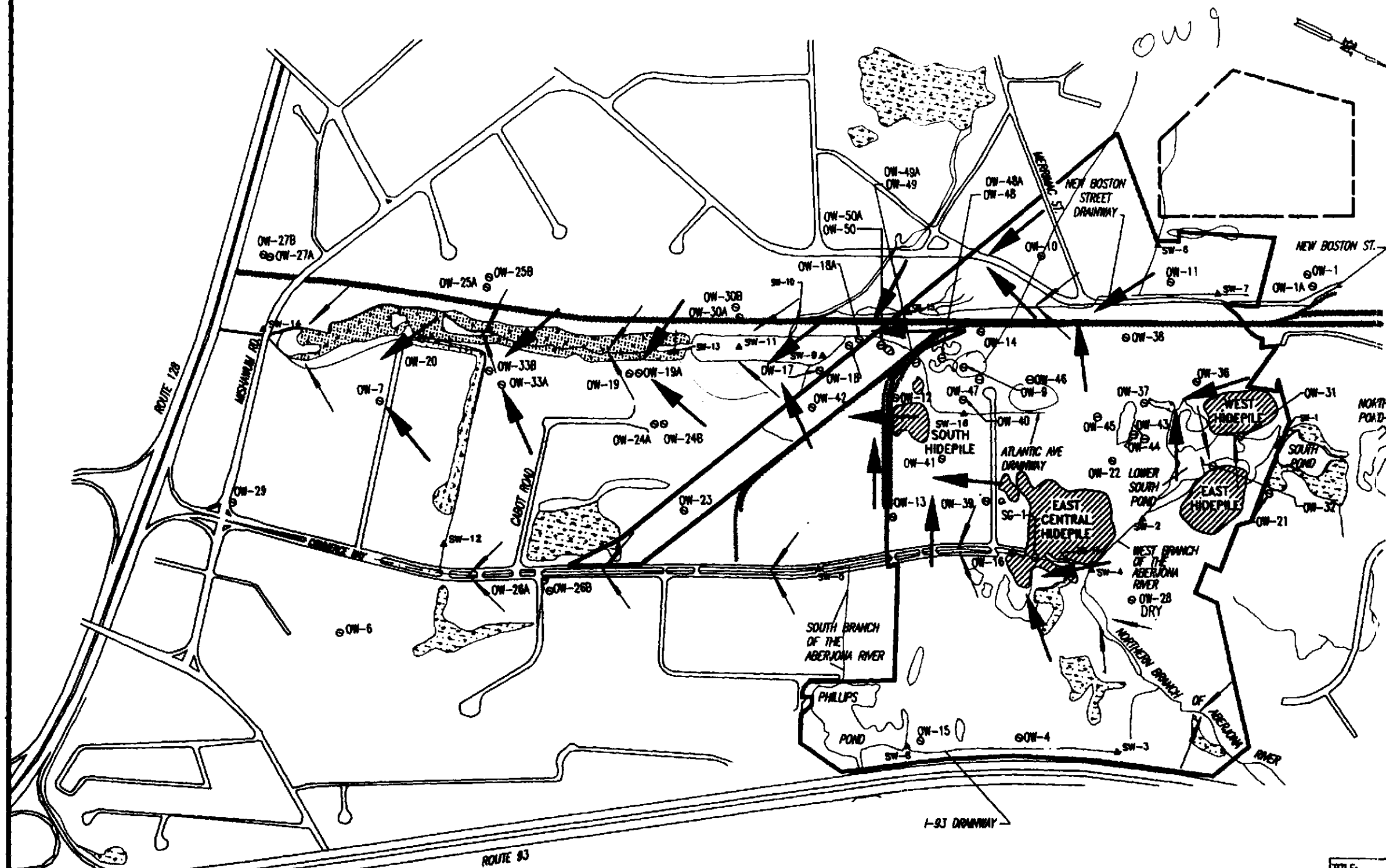
EXPLANATION

OW-21 OBSERVATION WELL LOCATION AND DESIGNATION

APPROXIMATE DIRECTION OF GROUND-WATER FLOW FOR "SHALLOWER" FLOW SYSTEM

APPROXIMATE DIRECTION OF GROUND-WATER FLOW FOR "DEEPER" FLOW SYSTEM

APPROXIMATE EXTENT OF WOBURN LANDFILL PROPERTY LINE, BASED UPON ENVIRONMENTAL SCIENCE & ENGINEERING, INC. FIGURE 1 (JULY 1990) AS CITED IN MAGUIRE GROUP (1989)

WETLANDS AREAS

TITLE:

CONCEPTUAL MODEL OF THE "SHALLOWER" AND "DEEPER" GROUND-WATER FLOW SYSTEM, INDUSTRI PLEX SITE, WOBURN, MASSACHUSETTS

PREPARED FOR:

INDUSTRI-PLEX REMEDIAL TRUST

ROUX
ROUX ASSOCIATES INC.
ENVIRONMENTAL CONSULTING & MANAGEMENT

COMPILED BY:	J.Y.	DATE:	05/91	FIGURE
PREPARED BY:	R.P./C.L.	SCALE:	AS SHOWN	
PROJECT MANAGER:	T.B.	REVISION:	0	4
PROJECT NO.		06609D		

HYDROGEOLOGIC CROSS-SECTION THROUGH PZ-1, PZ-2 AND ABERJONA RIVER

GROUND-WATER ELEVATIONS AND
VERTICAL HYDRAULIC GRADIENTS
OBSERVED FOR CLUSTER WELLS
MAY 13, 1991

EXPLANATION

100 = MARCH AND APRIL 1990 GSIP DATA

(100) = AUGUST 1990 GSIP DATA

100 = JUNE 1990 PHASE 1 PDI DATA

[100] = OCTOBER AND NOVEMBER PHASE 2 PDI DATA

—10— = 10 ug/L CONCENTRATION CONTOUR

▨ = 10 ug/L CONCENTRATION CONTOUR

NOTE: ALL WELLS WERE SAMPLED, ONLY
DETECTIONS ARE PRESENTED.
BENZENE DATA PRESENTED IN GREEN
TOLUENE DATA PRESENTED IN RED

0'   800'   1600'

TITLE:

DETECTED CONCENTRATIONS OF
BENZENE/TOLUENE
IN GROUND WATER

PREPARED FOR:

INDUSTRI-PLEX REMEDIAL TRUST

ROUX
ROUX ASSOCIATES, INC.
ENVIRONMENTAL CONSULTING
& MANAGEMENT

COMPILED BY:	J.Y.	DATE:	05/91	FIGURE
PREPARED BY:	R.P./C.L.	SCALE:	AS SHOWN	
PROJECT MANAGER:	T.B.	REVISION:	0	7
PROJECT NO.		06609D		

DETECTED CONCENTRATIONS OF DISSOLVED ARSENIC IN GROUNDWATER

EXPLANATION

100 = MARCH AND APRIL 1990 GSIP DATA

(100) = AUGUST 1990 GSIP DATA

100 = JUNE 1990 PHASE 1 PDI DATA

[100] = OCTOBER AND NOVEMBER PHASE 2 PDI DATA

—50— = 100 mg/L CONCENTRATION CONTOUR

WETLAND AREAS

NOTE: ALL WELLS WERE SAMPLED, ONLY DETECTIONS ARE PRESENTED.

TITLE:

DETECTED CONCENTRATIONS OF DISSOLVED ARSENIC IN GROUNDWATER

PREPARED FOR:

INDUSTRI—PLEX REMEDIAL TRUST

1600'

ROUX
ROUX ASSOCIATES, INC.
ENVIRONMENTAL CONSULTING & MANAGEMENT

COMPILED BY:	J.Y.	DATE:	05/91	FIGURE
PREPARED BY:	R.P./C.L.	SCALE:	AS SHOWN	**8**
PROJECT MANAGER:	T.B.	REVISION:	0	
PROJECT NO.		06609D		

DETECTED CONCENTRATIONS OF DISSOLVED CHROMIUM IN GROUND WATER
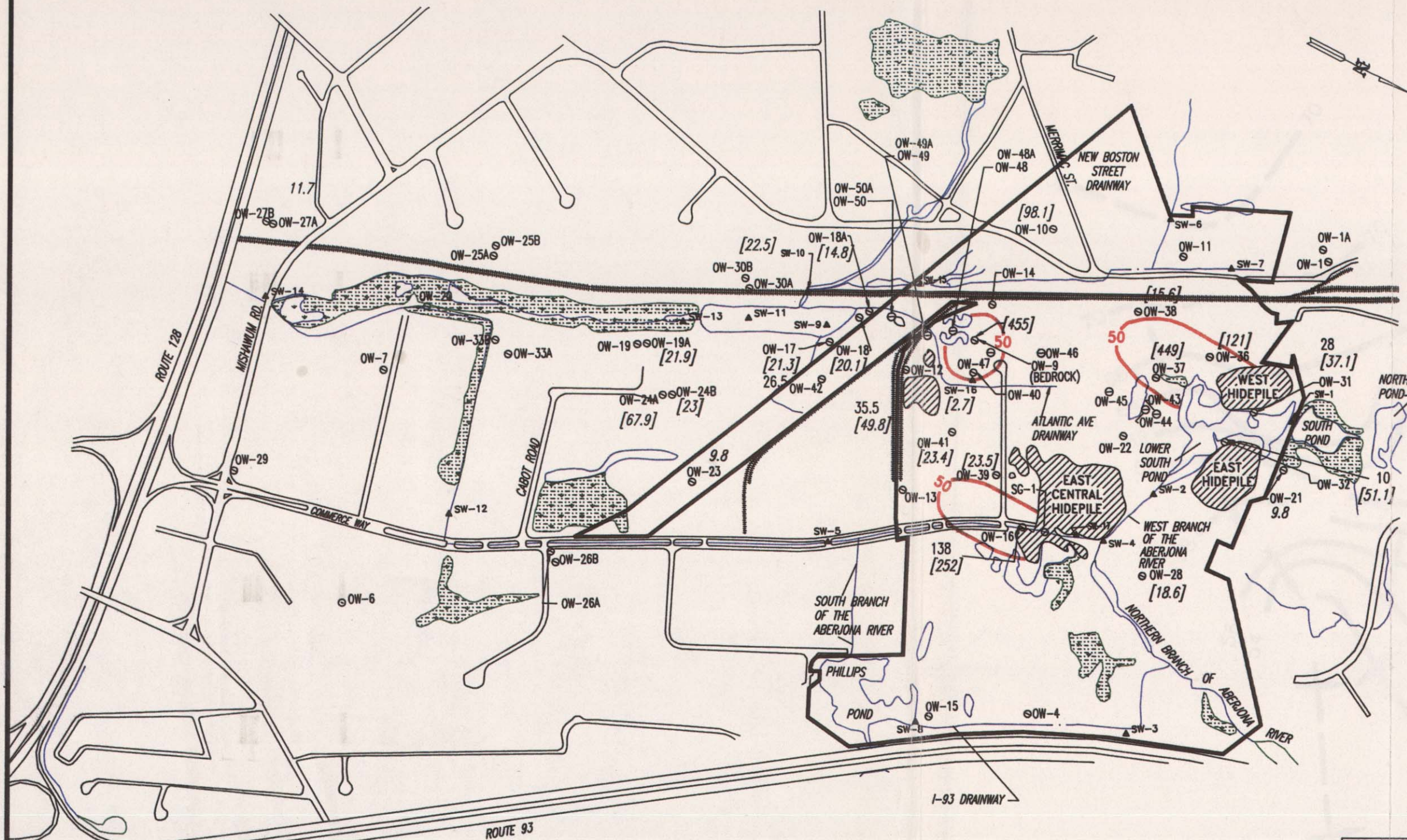
EXPLANATION

100 = MARCH AND APRIL 1990 GSIP DATA

(100) = AUGUST 1990 GSIP DATA

100 = JUNE 1990 PHASE 1 PDI DATA

[100] = OCTOBER AND NOVEMBER PHASE 2 PDI DATA

— 50 — = 50 ug/L CONCENTRATION CONTOUR

WETLAND AREAS

NOTE: ALL WELLS WERE SAMPLED, ONLY DETECTIONS ARE PRESENTED.

TITLE:

DETECTED CONCENTRATIONS OF DISSOLVED CHROMIUM IN GROUND WATER

PREPARED FOR:

INDUSTRI–PLEX REMEDIAL TRUST

ROUX
ROUX ASSOCIATES, INC.
ENVIRONMENTAL CONSULTING & MANAGEMENT

COMPILED BY:	J.Y.	DATE:	05/91	FIGURE
PREPARED BY:	R.P./C.L.	SCALE:	AS SHOWN	
PROJECT MANAGER:	T.B.	REVISION:	0	9
PROJECT NO.		06609D		

CONCENTRATION OF ARSENIC IN STREAM SEDIMENTS
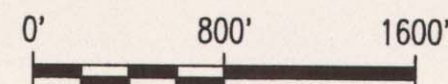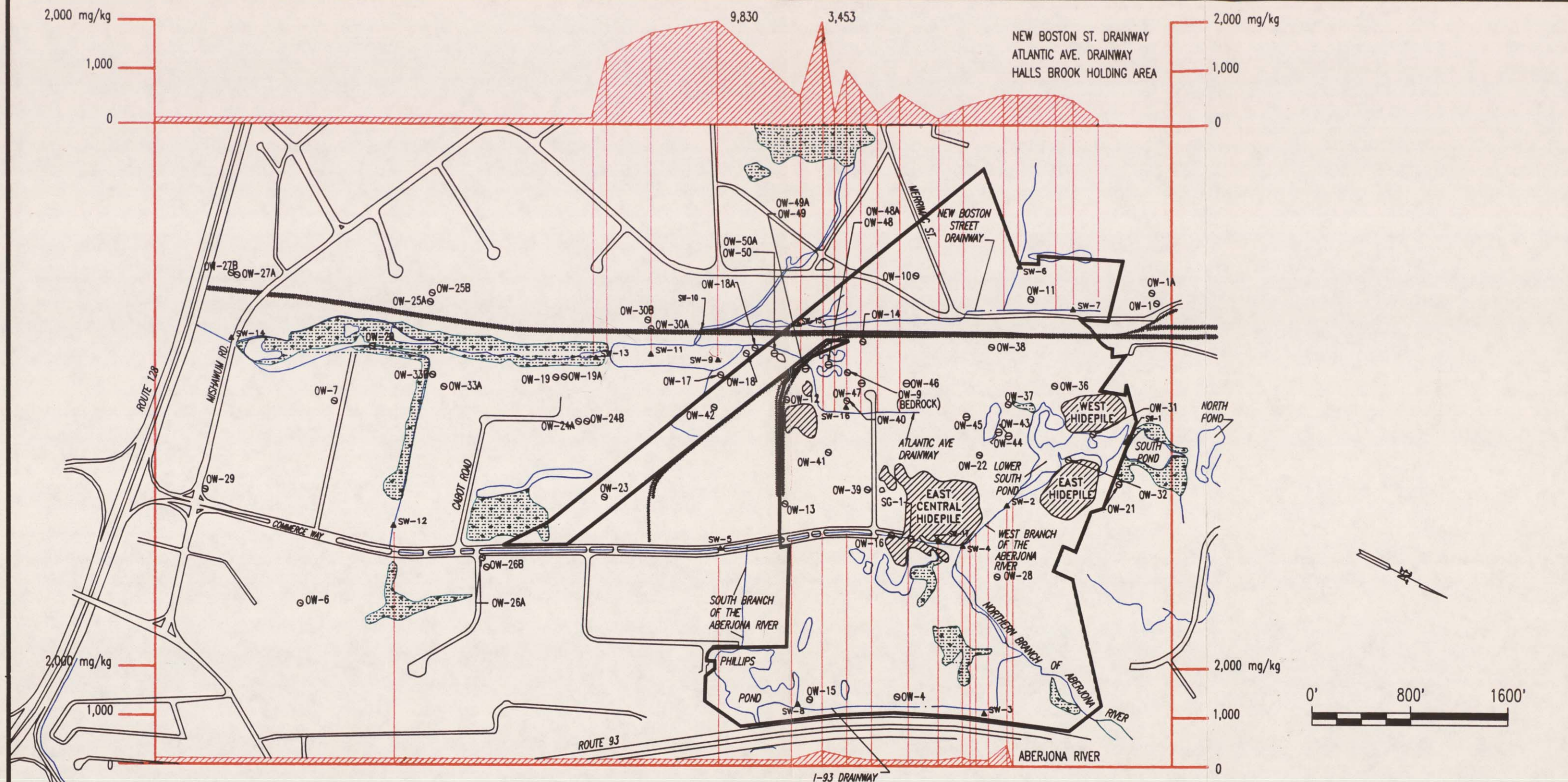
NOTES: 1. BASED ON GSIP DATA PROVIDED IN APPENDIX C AND PDI TASK SW-1 DATA.

2. INCLUDES DATA ONLY FROM SAMPLES COLLECTED IN SPECIFIED DRAINAGES.

3. WETLAND AREAS

TITLE:

CONCENTRATION
OF ARSENIC IN
STREAM SEDIMENTS

PREPARED FOR:

INDUSTRI—PLEX REMEDIAL TRUST

ROUX
ROUX ASSOCIATES, INC.
ENVIRONMENTAL CONSULTING & MANAGEMENT

COMPILED BY:	J.Y.	DATE:	05/91	FIGURE
PREPARED BY:	R.P./C.L.	SCALE:	AS SHOWN	10
PROJECT MANAGER:	T.B.	REVISION:	0	
PROJECT NO.		06609D		

CONCENTRATION OF TOTAL SEMI-VOLATILE ORGANIC COMPOUNDS IN STREAM SEDIMENTS
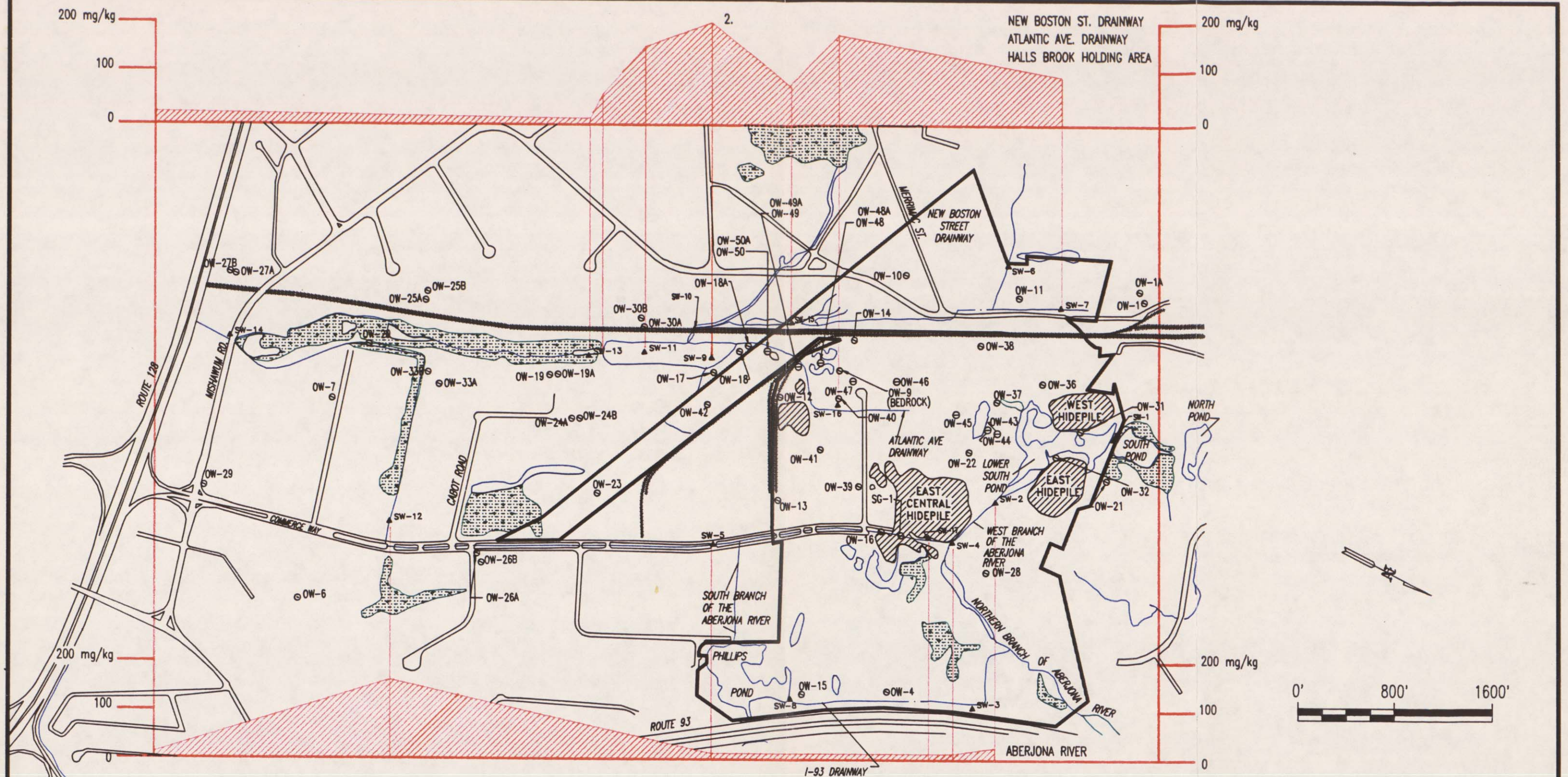
NOTES:

1. BASED ON GSIP DATA PROVIDED IN APPENDIX C (PDI TASK SW-1 SAMPLES NOT ANALYZED FOR SEMI-VOLATILE ORGANIC COMPOUNDS)

2. METHOD DETECTION LIMITS RANGED FROM 1,800 ppm TO 8,900 ppm, VALUE ASSUMED TO BE GREATER THAN 200ppm.

3. INCLUDES ONLY DATA FROM SAMPLES COLLECTED IN SPECIFIED DRAINAGES.

4. WETLAND AREAS

TITLE:

CONCENTRATION OF TOTAL
SEMI-VOLATILE ORGANIC
COMPOUNDS IN STREAM SEDIMENTS

PREPARED FOR:

INDUSTRI-PLEX REMEDIAL TRUST

ROUX
ROUX ASSOCIATES, INC.
ENVIRONMENTAL CONSULTING
& MANAGEMENT

COMPILED BY:	J.Y.	DATE:	05/91	FIGURE
PREPARED BY:	R.P./C.L.	SCALE:	AS SHOWN	
PROJECT MANAGER:	T.B.	REVISION:	0	11
PROJECT NO.	06609D			

Figure 12

Arsenic Concentrations in Sediment

vs. Distance (Aberjona River)

$Y = X^{-0.4029} \times 709.68$

◄PDI SW1/028

*◄SW-14

Arsenic Concentration (ppm)

Distance from Lower South Pond (ft)

Figure 13

Chromium Concentrations in Sediment
vs. Distance (Aberjona River)

$$Y = X^{-0.425} \times 1674.75$$

Figure 14

Lead Concentrations In Sediment

vs. Distance (Aberjona River)

$Y = X^{-0.481} \cdot X \quad 2621.11$

◄ PDI SW1/028

◄ SW-14

Lead Concentration (ppm)

Distance from Lower South Pond (ft)
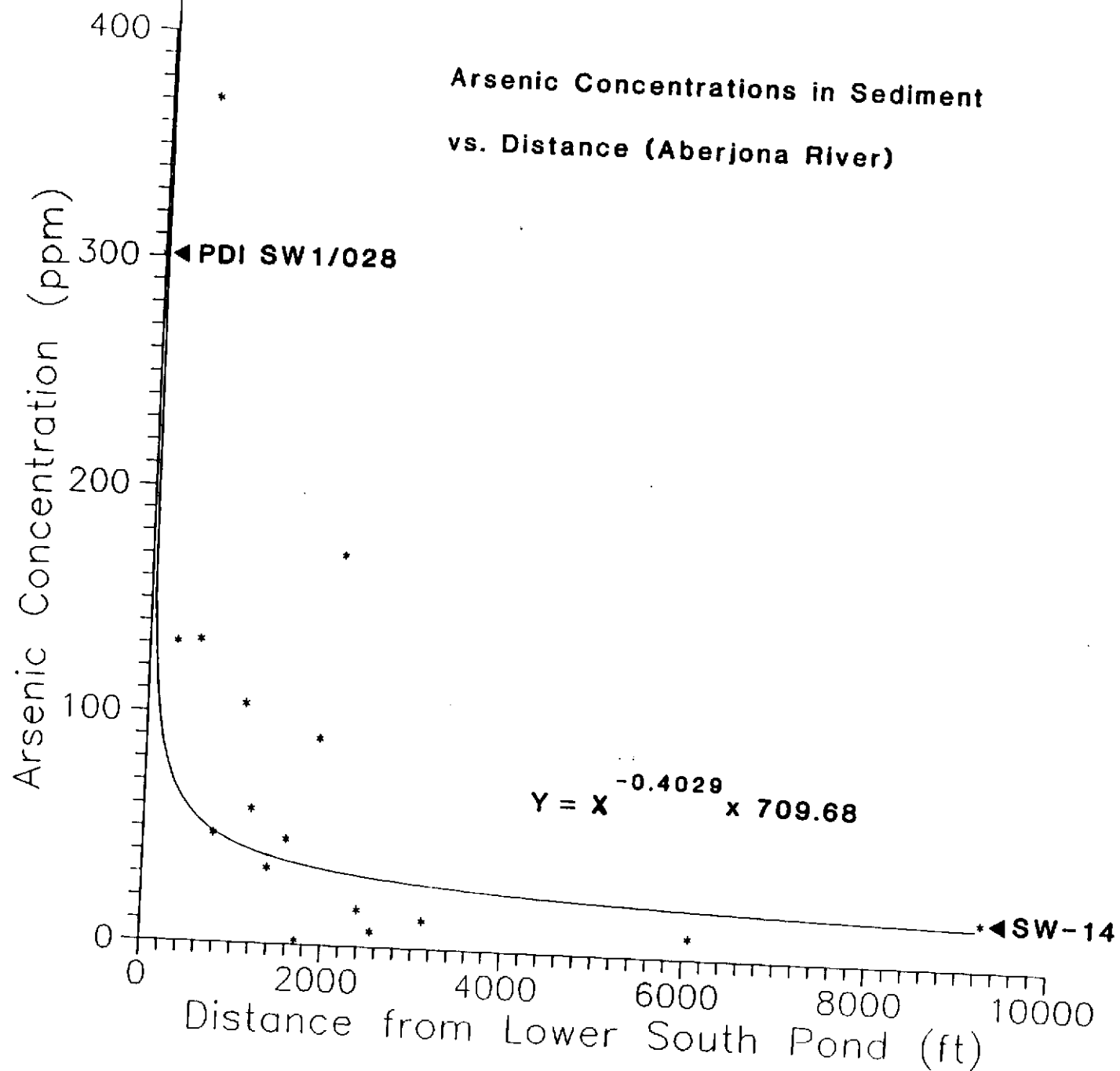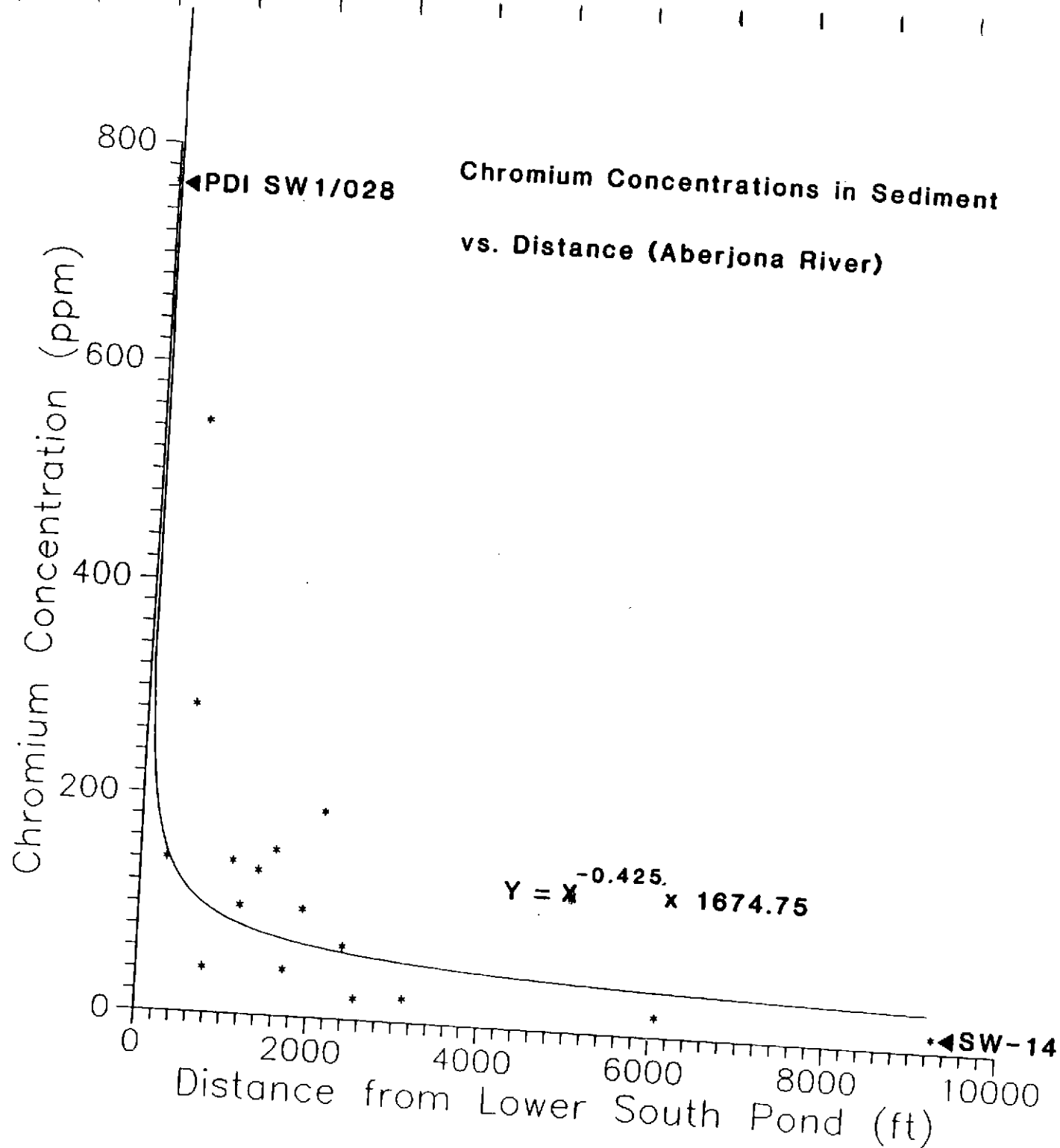
Figure 15
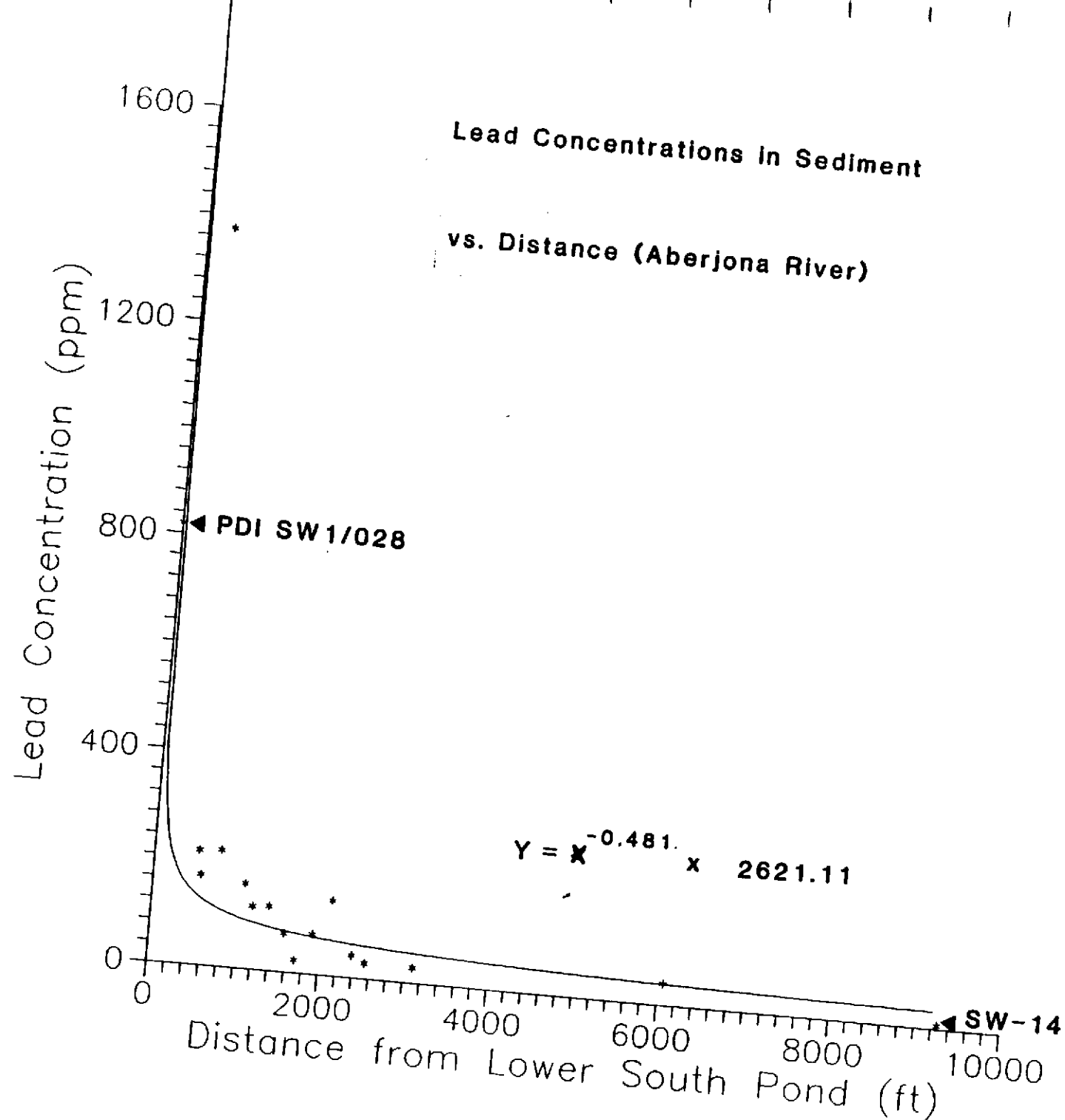
Relationship Between Cadmium and Zinc
in the
Hall's Brook Holding Area Sediments

CH$_3$SH
H$_2$S

OW-28

East Hide Pile

Cr(VI)

East Central Hide Pile

CH$_2$O

Pyrite Waste / Pb$_3$(AsO$_4$)$_2$ // Zn$_3$(AsO$_4$)$_2$

OW-7

H$_2$SO$_{4(aq)}$

CaCO$_{3(s)}$

Cr(III)   Pb^{+2} As(V)

Fe^{+2}

Fe,Cr$_{(1-x)}$(OH)$_{3(s)}$

Cr(OH)$_{3(s)}$

CaSO$_4$2H$_2$O$_{(s)}$ — →H$_2$CO$_3^*_{(aq)}$ + Acetate · [Alkalinity

Halls Brook Holding Area

Wetlands

CH$_3$ As(III)

As(V)   O$_2$

As(III)
H$_3$AsO$_3^*$
MMAA
DMAA

As(V)
HAsO$_4^{-2}$
H AsO$_4$

As(III)

Cr-acetate

AQUIFER

CROSS-SECTION

(pesticide residues)

As(V) —(5)→ As(III)

CH$_2$O (6)
(organic matter, hide piles)
→ CH$_3$

(7)

MMAA (8) → DMAA (Mobile)

Total alkalinity
CH$_3$CO$^-$ (acetate)
CO$_3^{-2}$

CH$_3$HS (methyl mercaptan)
H$_2$S (hydrogen sulfide)
} degas from hide piles

CaCO$_3$ (calcite)

(4)

Cr-Acetate (major species)

(13) Ca^{+2}

Cr(VI) — Cr (III)
(hide piles)

CaSO$_4$.2H$_2$O (gypsum)

SO$_4^{-2}$

Cr(OH)$_3^o$ (minor species)

} (Mobile)

FeS$_2$ (pyrite) (2) → Fe^{2+} (3) → Fe(OH)$_3$(s)

(11) → Cr$_{0.25}$Fe$_{0.75}$ (OH)$_{3(s)}$ (precipitate)

O$_2$

Sorption

Cd^{+2} Cu^{+2} Hg^{+2} Pb^{+2}

CONCEPTUALIZED INTERACTION BETWEEN ORGANIC AND INORGANIC CONSTITUENTS

CIRCLED NUMBERS REFER TO EQUATIONS IN TEXT

$$FeS_2 + 4.25 O_2 + 2.5 H_2O \rightleftharpoons Fe(OH)_3 + 2H^+ + 2SO_4^{-2} \qquad \text{(Eq. 1)}$$

$$FeS_2 + 14Fe^{3+} + 8H_2O \rightleftharpoons 15Fe^{+2} + 2SO_4^{-2} + 16H^+ \qquad \text{(Eq. 2)}$$

$$Fe^{2+} + 3H_2O \rightleftharpoons Fe(OH)_{3(s)} + 3H^+ + e^-. \qquad \text{(Eq. 3)}$$

$$SO_4^{-2} + CH_2O + O_2 + 10H^+ + 8e^- \rightleftharpoons H_2S + CO_2 + 5H_2O \qquad \text{(Eq. 4)}$$

$$H_3AsO_4^* + 2H^+ + 2e^- \rightleftharpoons H_3AsO_3^* + H_2O \qquad \text{(Eq. 5)}$$

$$CH_2O + 2H^+ + 2e^- \rightleftharpoons CH_3OH \qquad \text{(Eq. 6)}$$

$$CH_3OH + H_3AsO_3^* \rightleftharpoons CH_3AsO(OH)_2 + H_2O \qquad \text{(Eq. 7)}$$

$$CH_3AsO(OH)_2 + CH_3OH + 2H^+ + 2e^- \rightleftharpoons (CH_3)_2AsO(OH) + 2H_2O \qquad \text{(Eq. 8)}$$

$$Cr(OH)_2^+ + H_2O \rightleftharpoons Cr(OH)_{3(s)} + H^+ \qquad \text{(Eq. 9)}$$

$$Cr(OH)_2^+ + 3Fe^{+3} + 10H_2O \rightleftharpoons 4\{Cr_{0.25}Fe_{0.75}(OH)_3\} + 10H^+ + e^- \qquad \text{(Eq. 10)}$$

$$H_2O + Cr(OH)_2 + 3Fe(OH)_{3(s)} \rightleftharpoons 4[Cr0.25Fe0.75(OH)_3] + H^+ \qquad \text{(Eq. 11)}$$

$$0.75Fe^{+2} + 0.25H_2CrO_4^* + 2H_2O \rightleftharpoons Cr_{0.25}Fe_{0.75}(OH)_3 + 1.5H^+ + e^- \qquad \text{(Eq. 12)}$$

$$2H_2O + H_2SO_4 + CaCO_{3(s)} \rightleftharpoons CaSO_4.2H_2O_{(s)} + H_2CO_3 \qquad \text{(Eq. 13)}$$

EQUATIONS

FIGURE 17. DISTRIBUTION OF Eh-pH MEASUREMENTS OF NATURAL AQUEOUS ENVIRONMENTS (FROM BAAS BECKING ET AL. 1960)
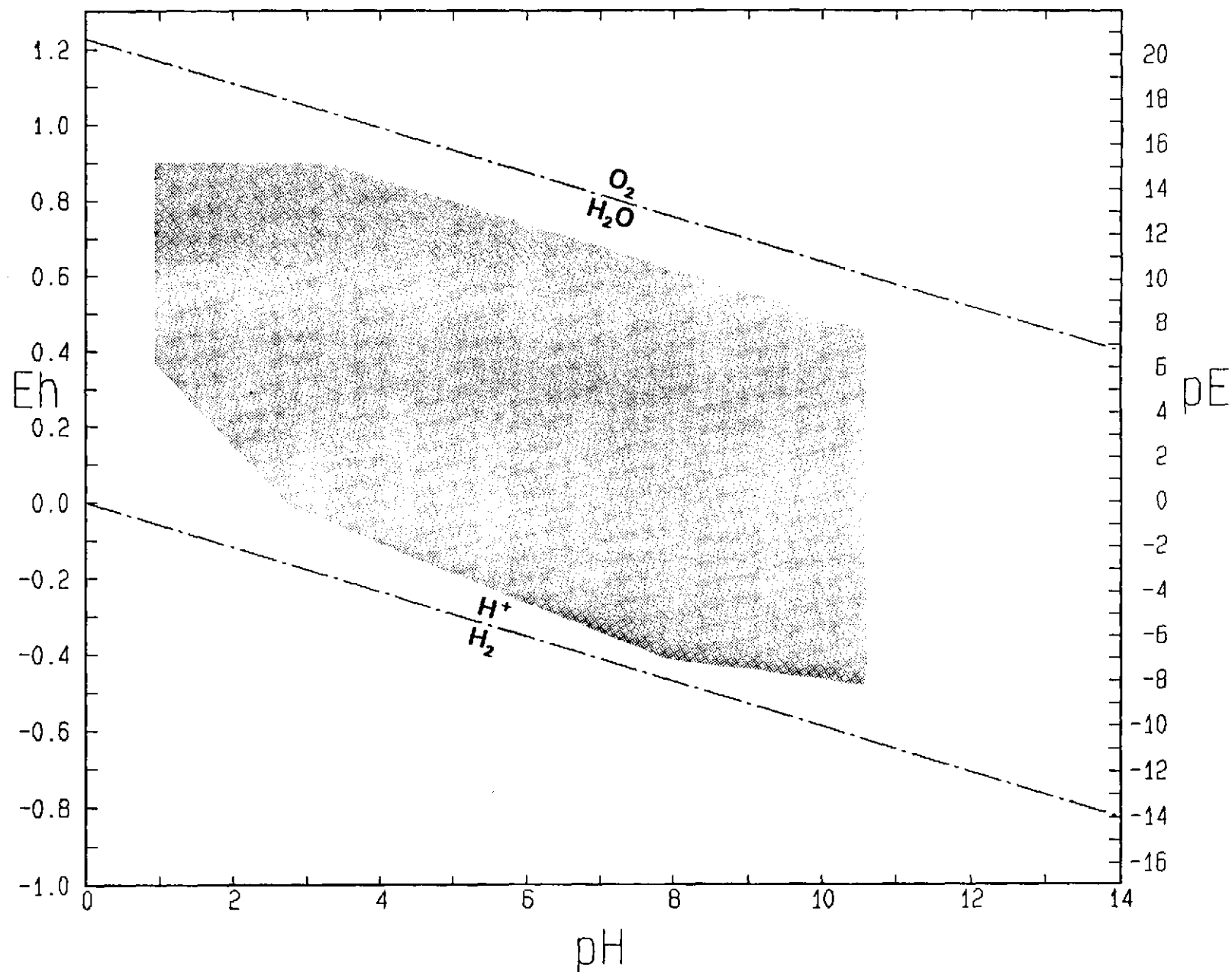
FIGURE18. Eh-pH DIAGRAM FOR Fe SPECIES. $\Sigma Fe = 1E-5$, $\Sigma C = 1E-2$, $\Sigma S = 5E-3$. SCREENED AREA REPRESENTS Eh-pH MEASUREMENTS IN GROUNDWATER, MARCH, APRIL, AND AUGUST 1990, INDUSTRI-PLEX SITE, WOBURN, MASSACHUSETTS
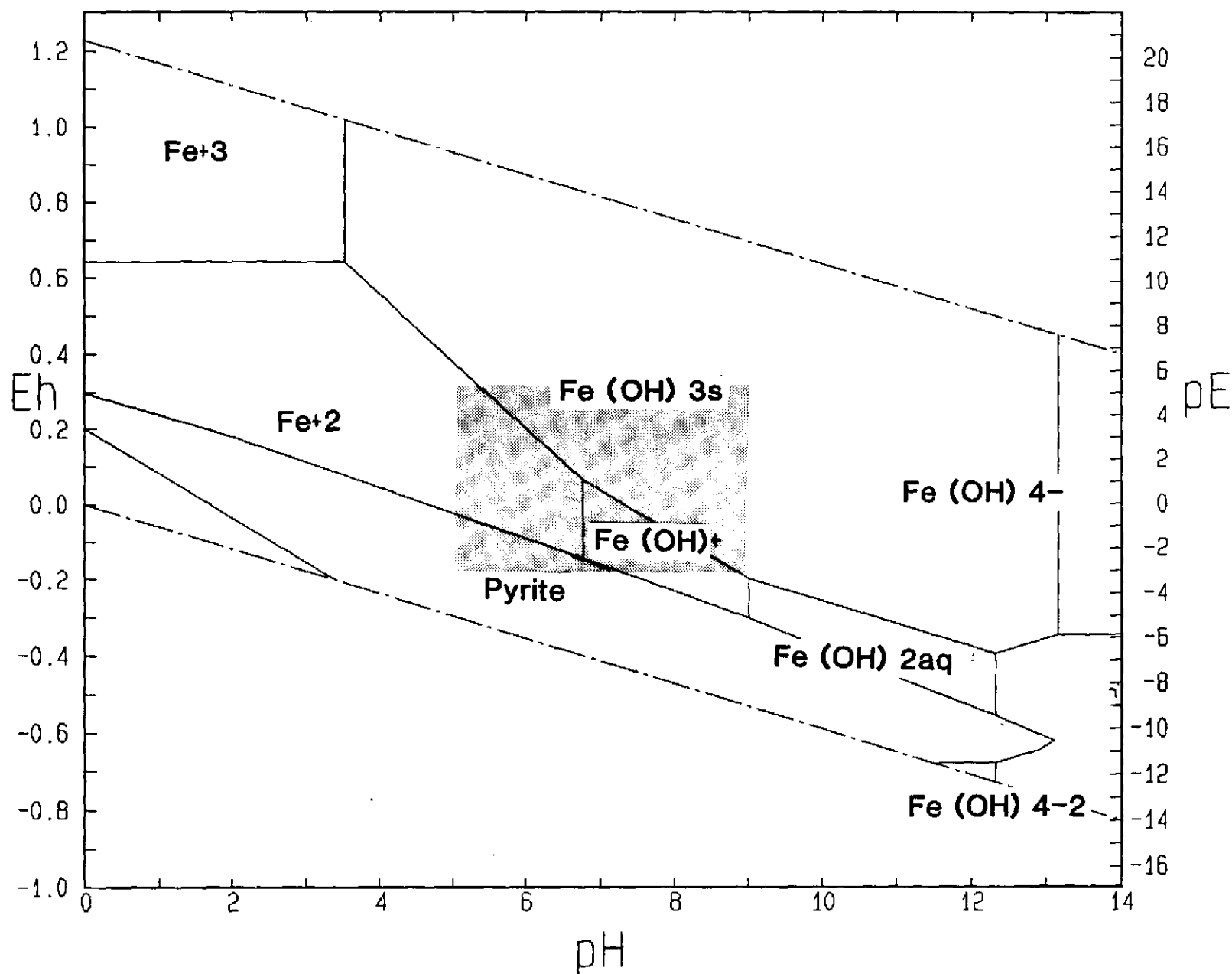
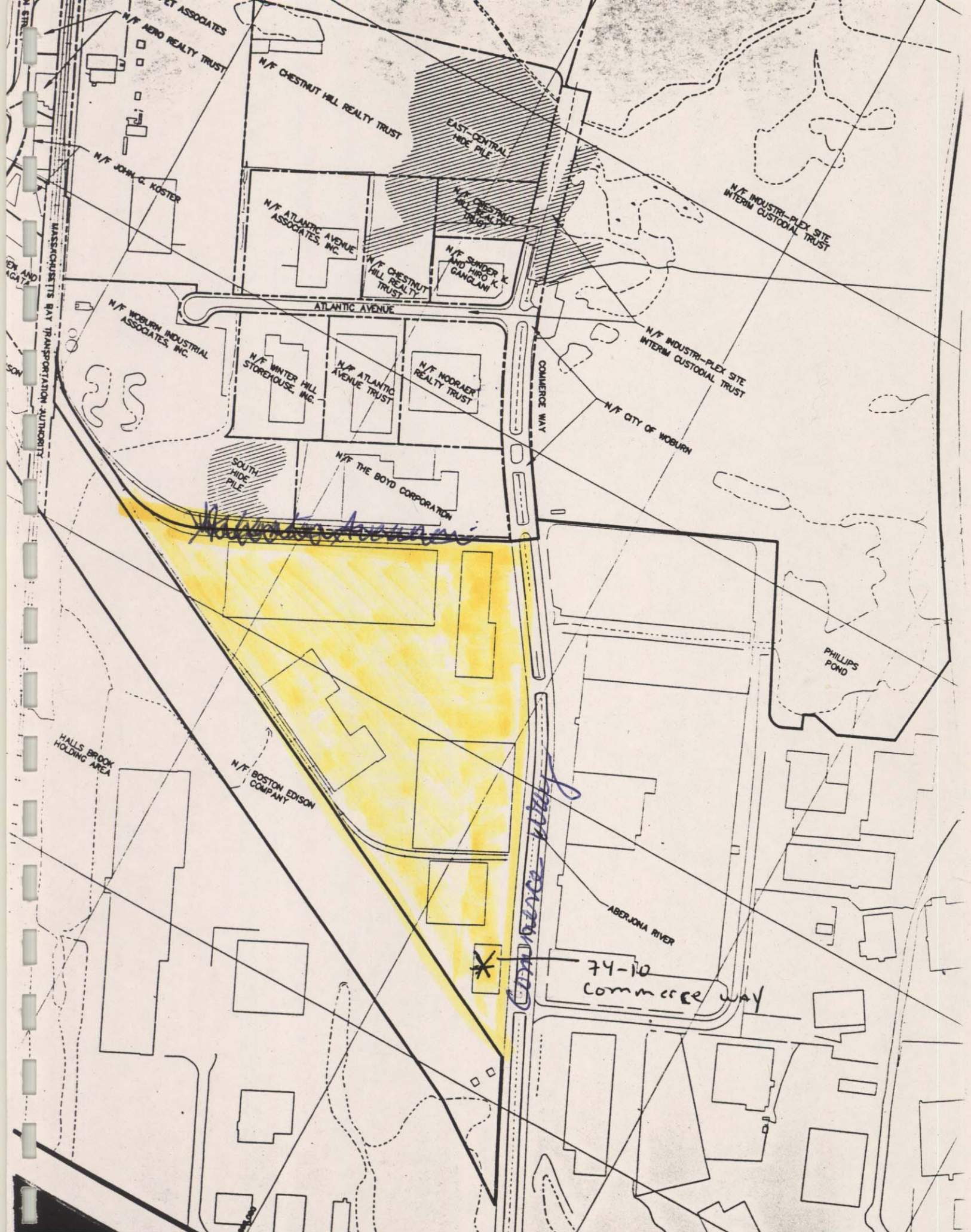FIGURE 19. HALF-LIVES FOR AQUEOUS Fe(II) AS A FUNCTION OF pH AT 25°C*

Typical pH range
of Industri-Plex
waters.
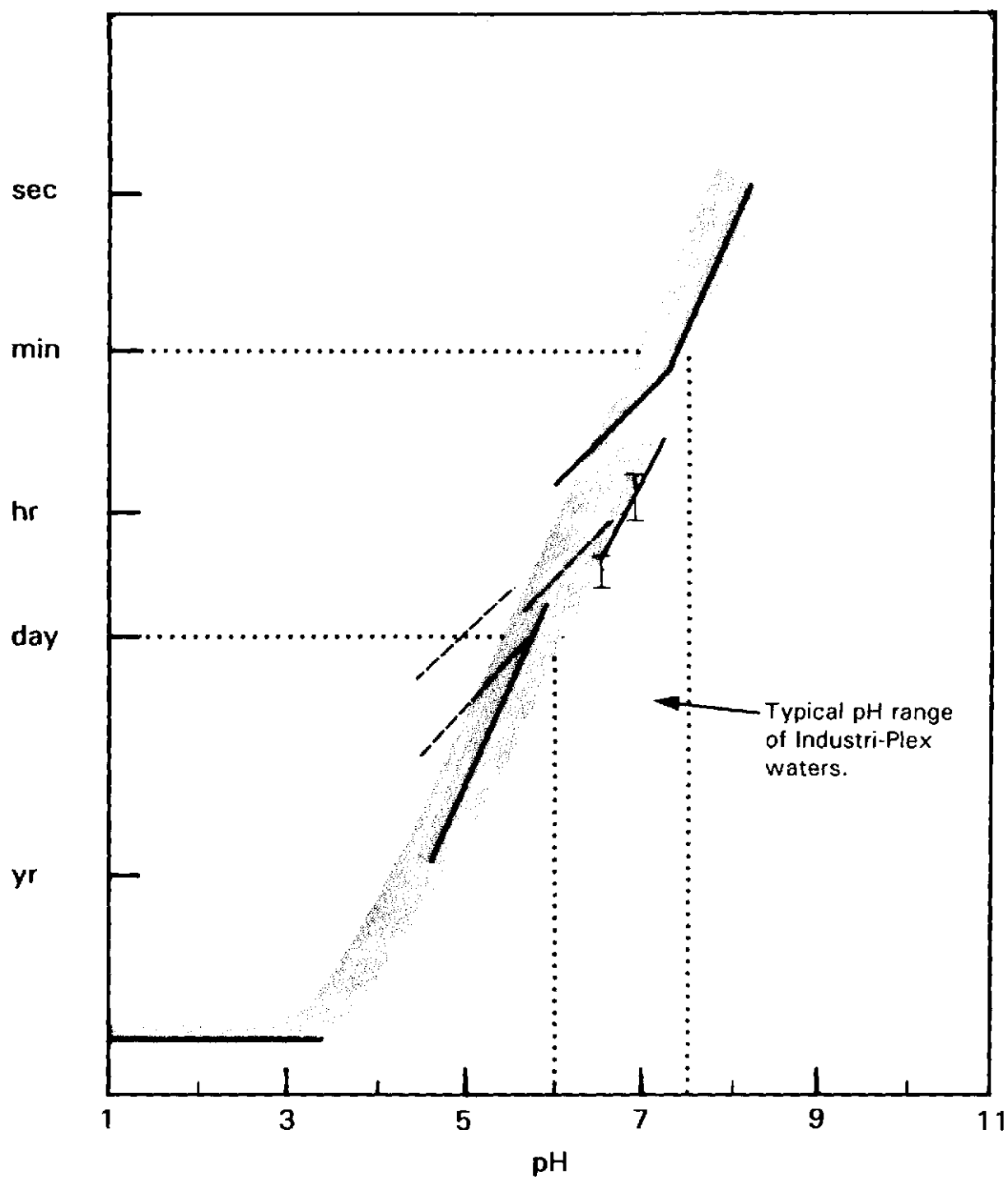
Data Sources:

Tamura et al. 1976.
Sung and Morgan. 1980.
Singer and Stumm. 1970.
Davison and Seed. 1983.
Roekens and VanGrieken. 1983.

*From Eary & Rai. 1988. Environ. Sci. & Tech. 22:972-977.

FIGURE 20. THEORETICAL Fe SPECIES IN MONITORING WELLS BASED ON Eh-pH MEASUREMENTS, MARCH, APRIL, AND AUG. 1990, INDUSTRI-PLEX SITE, WOBURN, MASSACHUSETTS
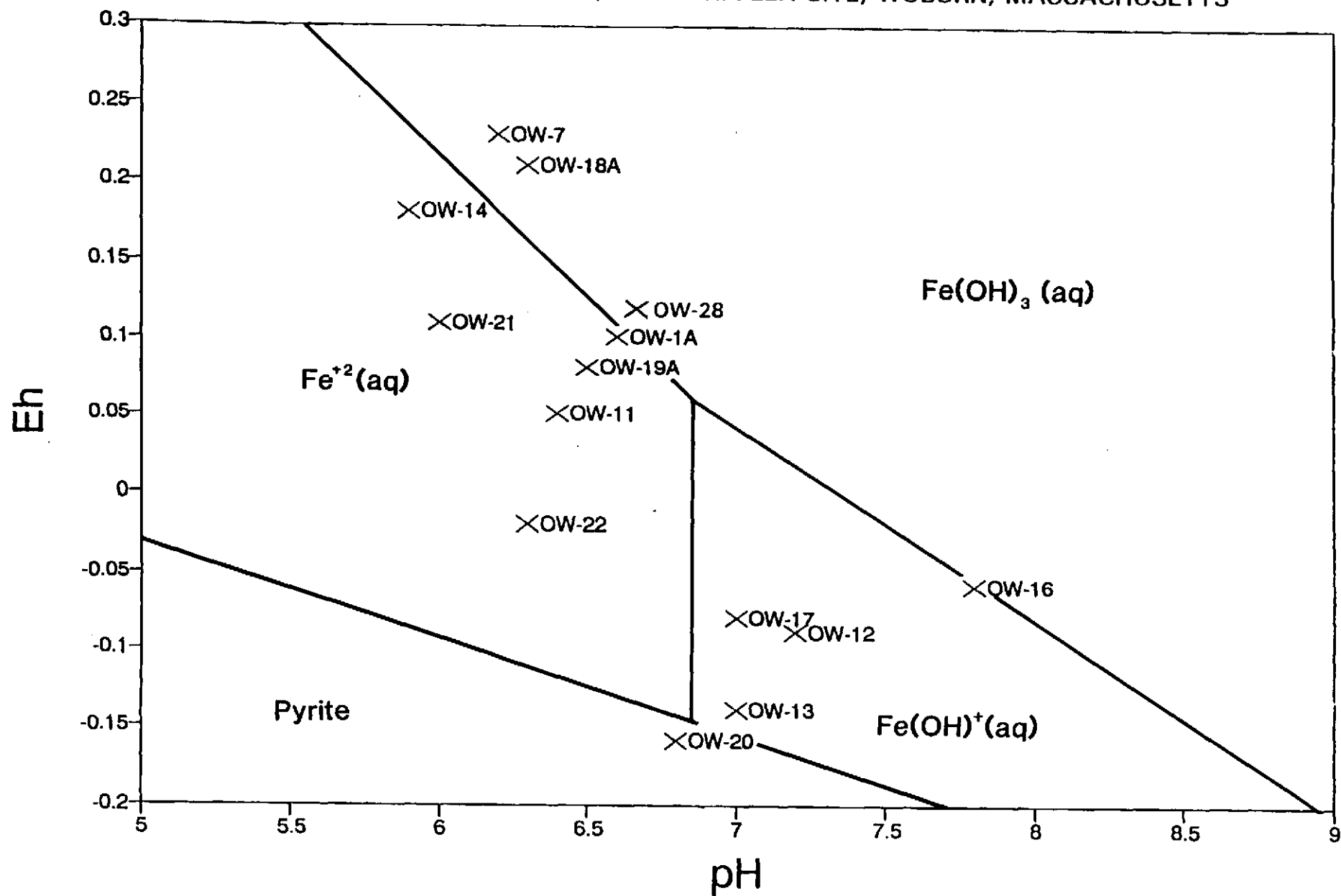
FIGURE 21. Eh-pH DIAGRAM FOR As SPECIES. $\Sigma As = 1E-5$, $\Sigma Cu = 1E-7$. SCREENED AREA REPRESENTS pH/Eh MEASUREMENTS IN GROUNDWATER, MARCH, APRIL, AND AUG. 1990, INDUSTRI-PLEX SITE, WOBURN, MASSACHUSETTS
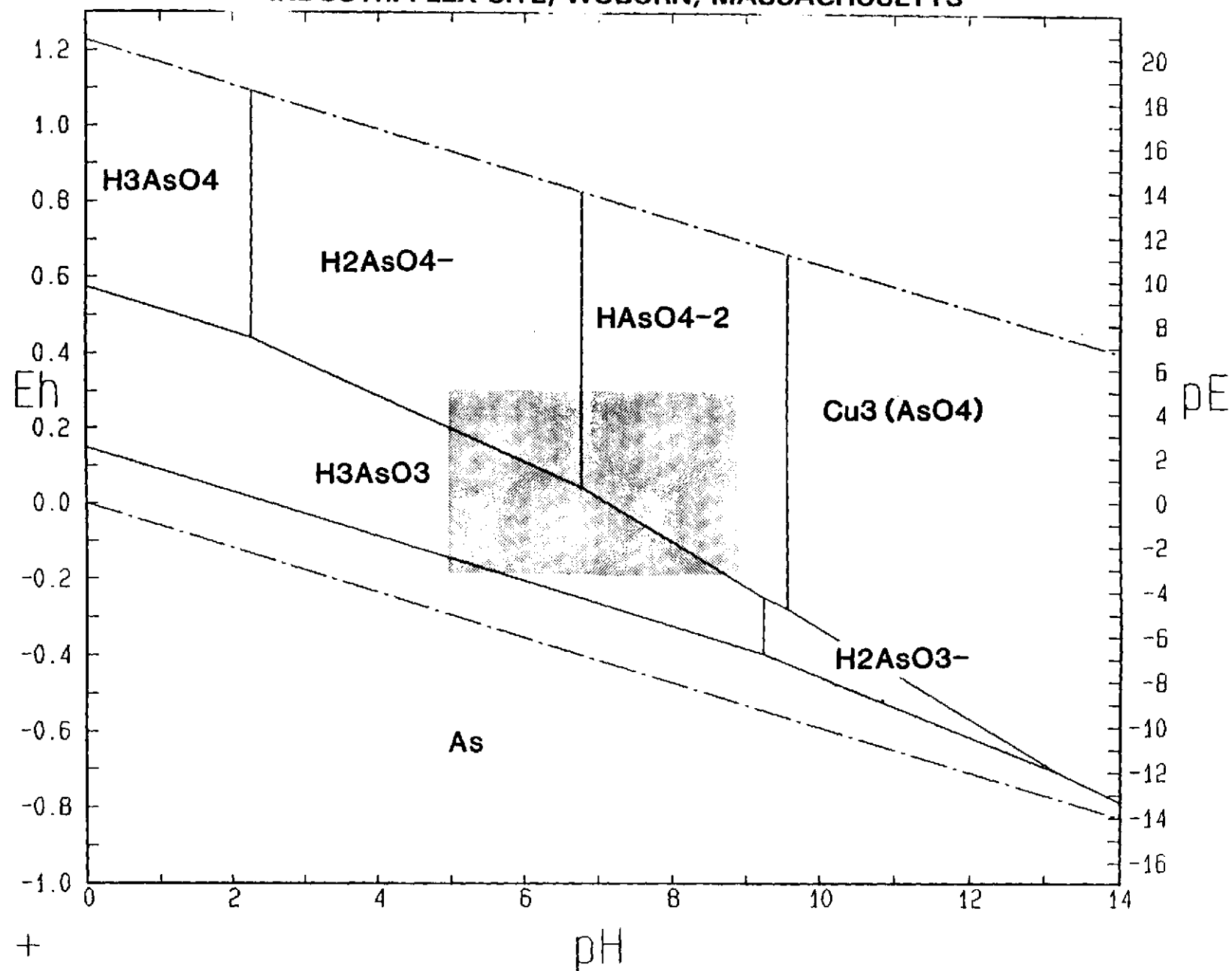
FIGURE22. THEORETICAL As SPECIES IN MONITORING WELLS BASED ON Eh-pH MEASUREMENTS, MARCH, APRIL, AND AUG. 1990, INDUSTRI-PLEX SITE, WOBURN, MASSACHUSETTS
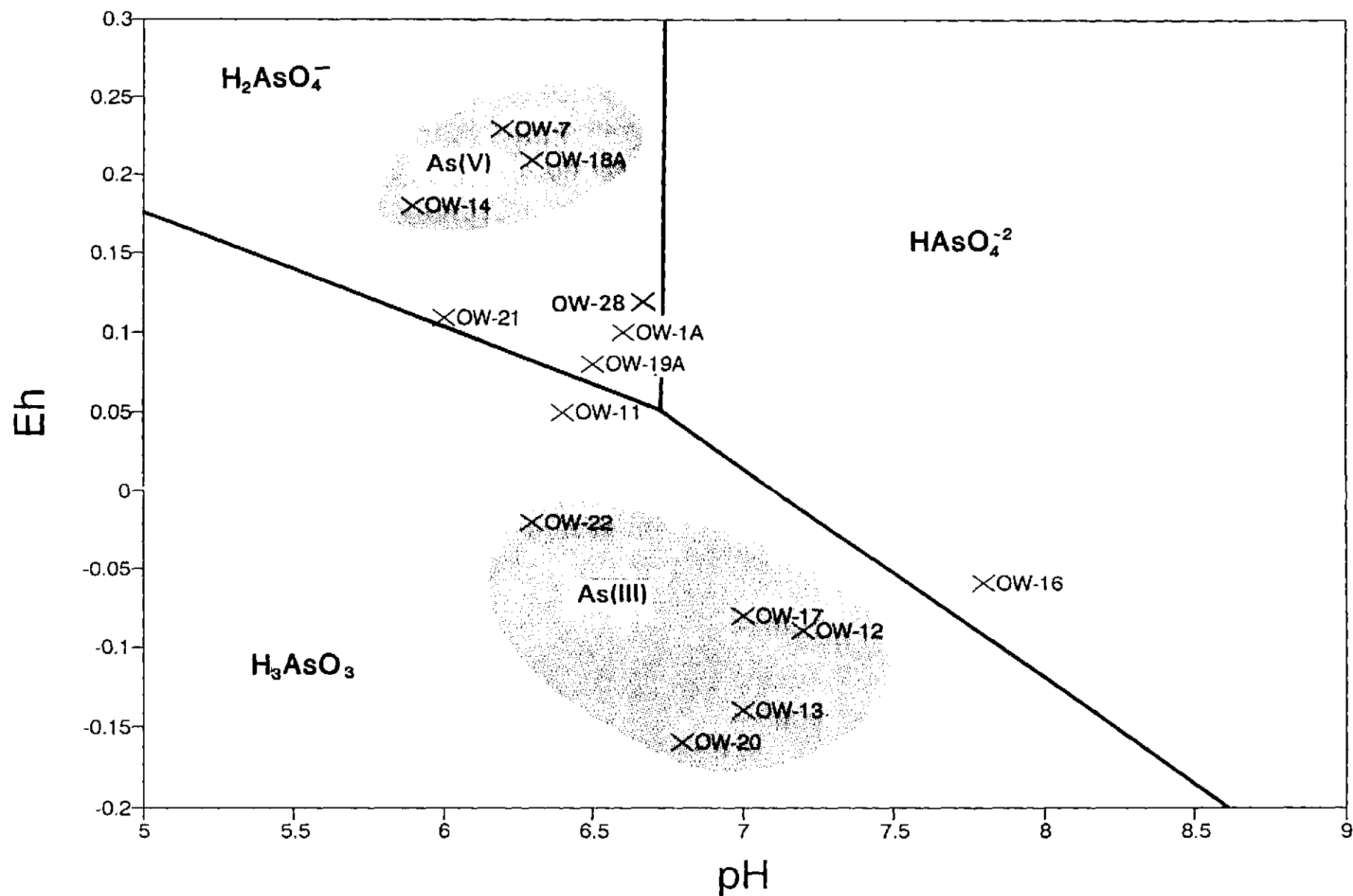
FIGURE 23. pH-ADSORPTION EDGE FOR ARSENATE ON am-Fe(OH)$_3$: EFFECTS OF TOTAL IRON AND TOTAL ARSENATE (FROM LECKIE ET AL. 1980)

ADSORPTION I 0.1 NaNO$_3$, 25 °C

⬡ 5.0×10^{-5} As$_T$; 4.0×10^{-4} Fe$_T$
△ 5.0×10^{-5} As$_T$; 6.0×10^{-4} Fe$_T$
○ 5.0×10^{-5} As$_T$; 8.0×10^{-4} Fe$_T$
☐ 5.0×10^{-5} As$_T$; 1.0×10^{-3} Fe$_T$
◇ 5.0×10^{-6} As$_T$; 1.0×10^{-3} Fe$_T$
▷ 5.0×10^{-7} As$_T$; 1.0×10^{-3} Fe$_T$

PERCENT As ADSORBED

pH
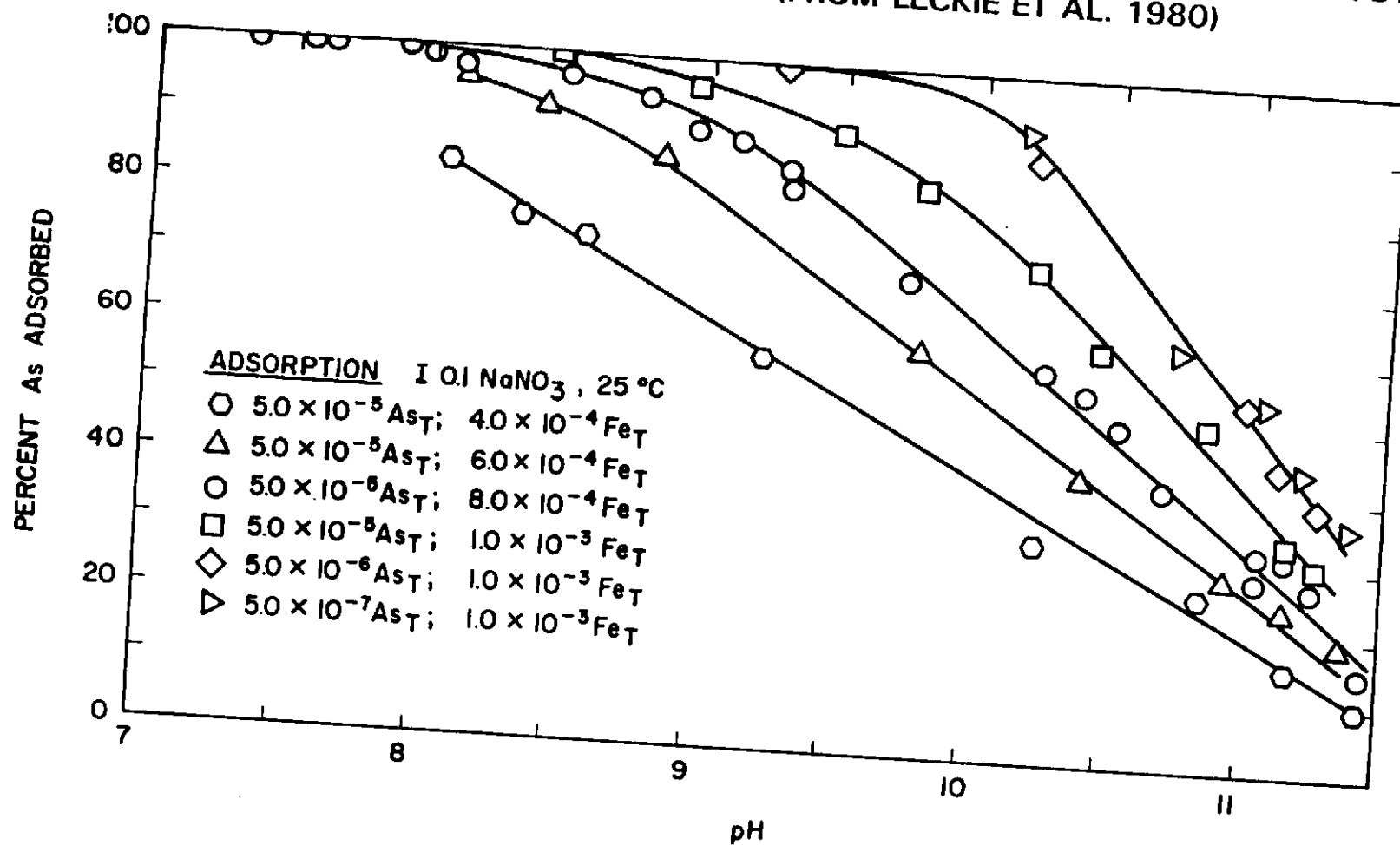
FIGURE 24. BIOLOGICAL CYCLE FOR ARSENIC
(FROM FAUST & ALY, *CHEMISTRY OF NATURAL WATERS,* 1981)
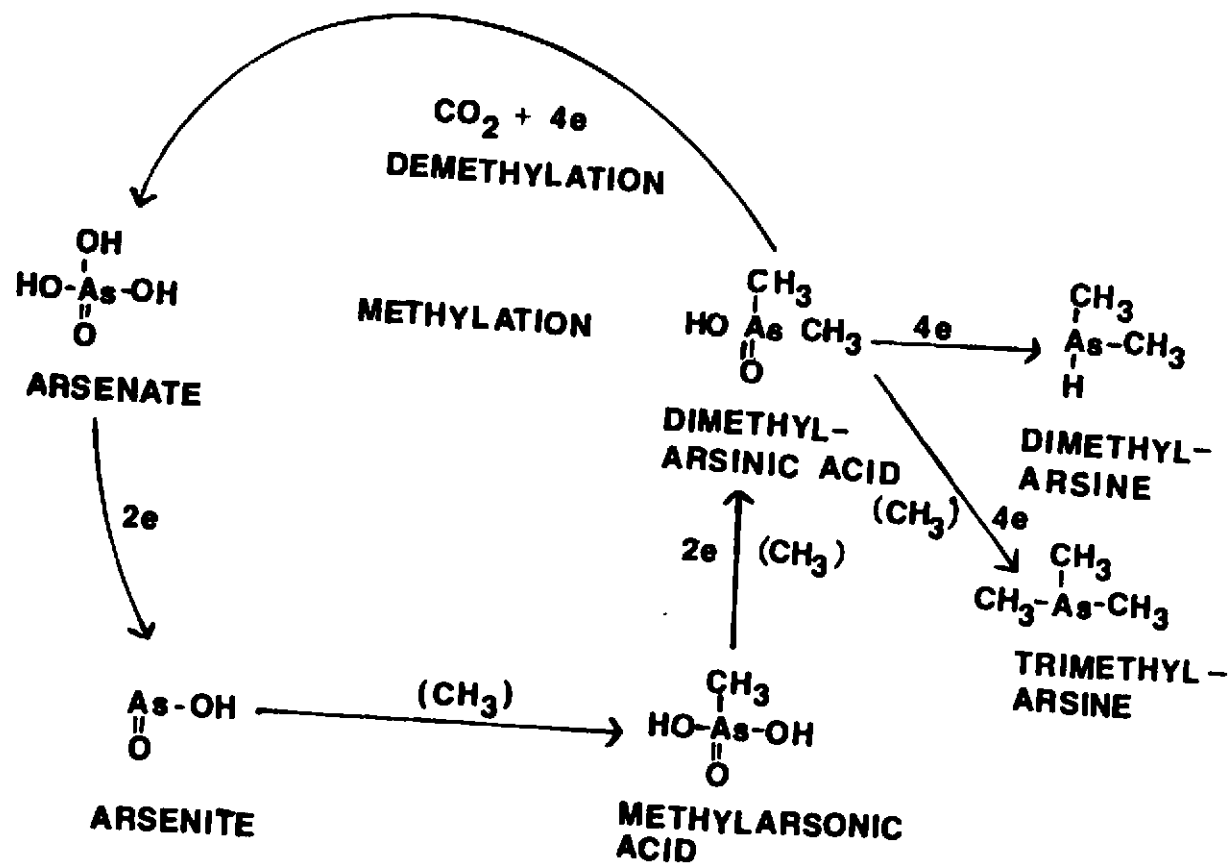
FIGURE 25. MOBILITY OF DIFFERENT ARSENIC SPECIES IN RIVER SEDIMENTS (FROM HOLM ET AL., *CHEMICAL MODELING IN AQUEOUS SYSTEMS*, 1980)
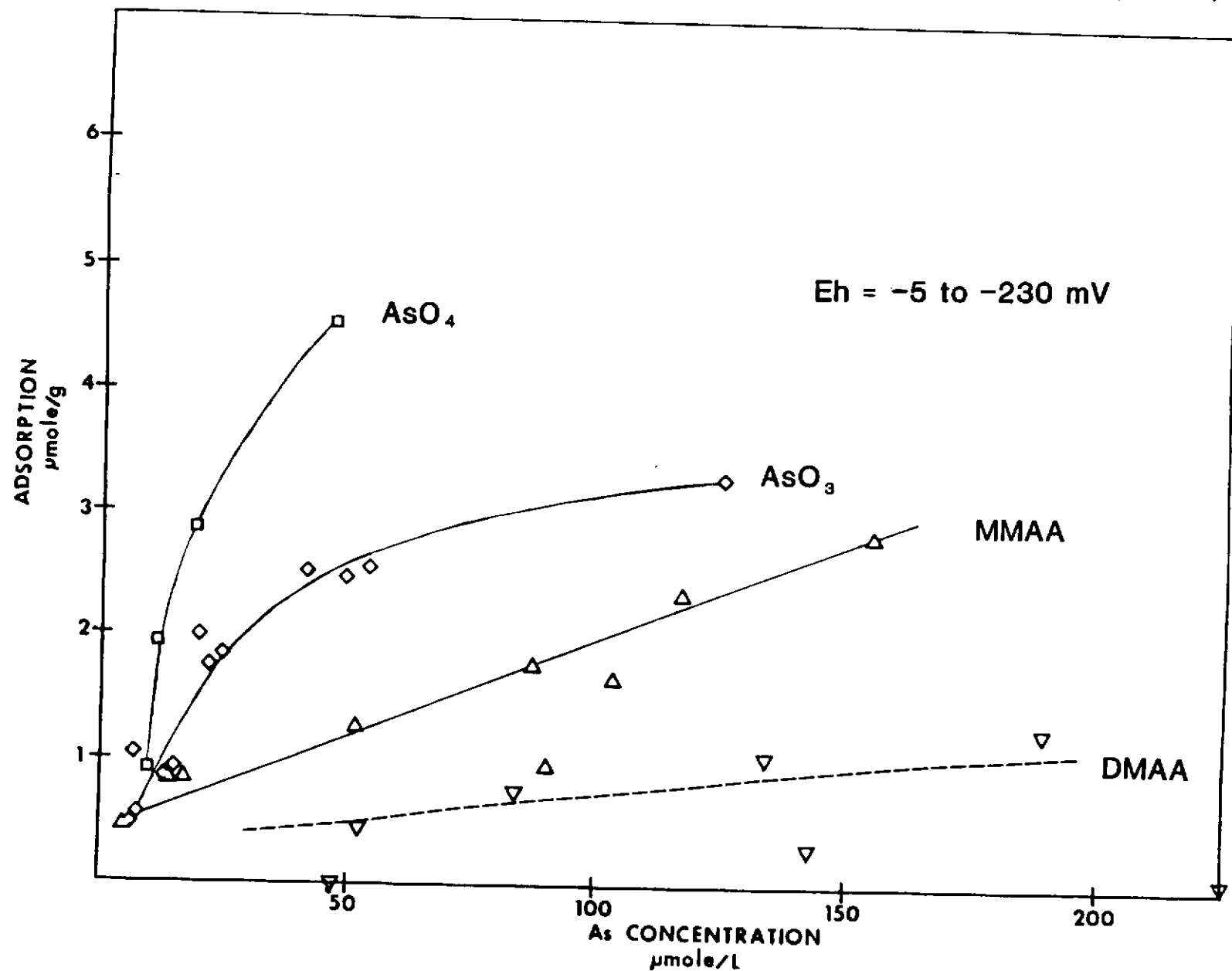
FIGURE 26. Eh-pH DIAGRAM FOR Cr SPECIES. $\Sigma Cr = 1E\text{-}5$, $\Sigma Fe = 1E\text{-}5$. SCREENED AREA REPRESENTS Eh-pH MEASUREMENTS IN GROUNDWATER, MARCH, APRIL, AND AUG. 1990, INDUSTRI-PLEX SITE, WOBURN, MASSACHUSETTS
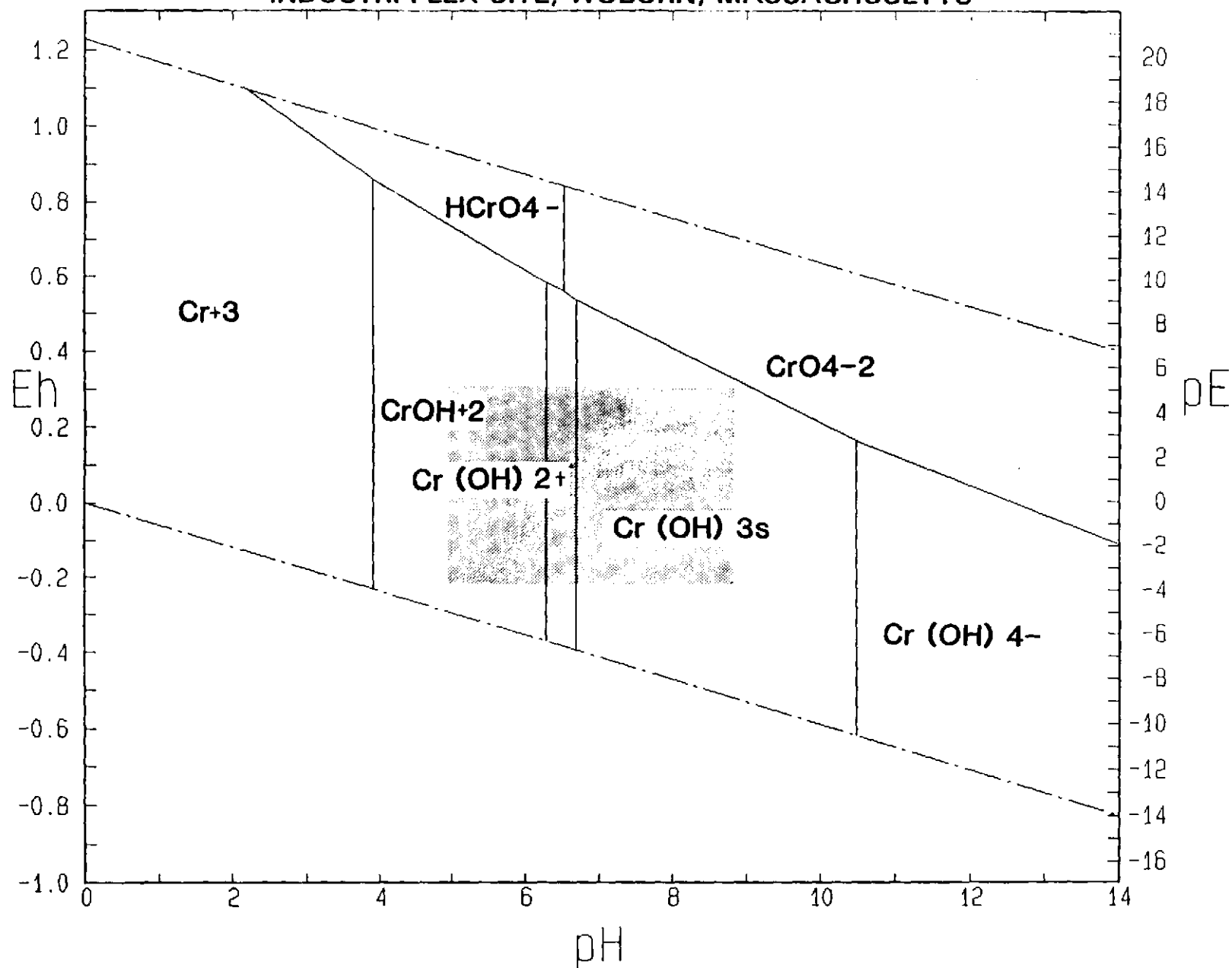
FIGURE 27. CHROMATE ADSORPTION TO SINGLE-PHASE SORBENTS (FROM RAI ET AL. 1988)
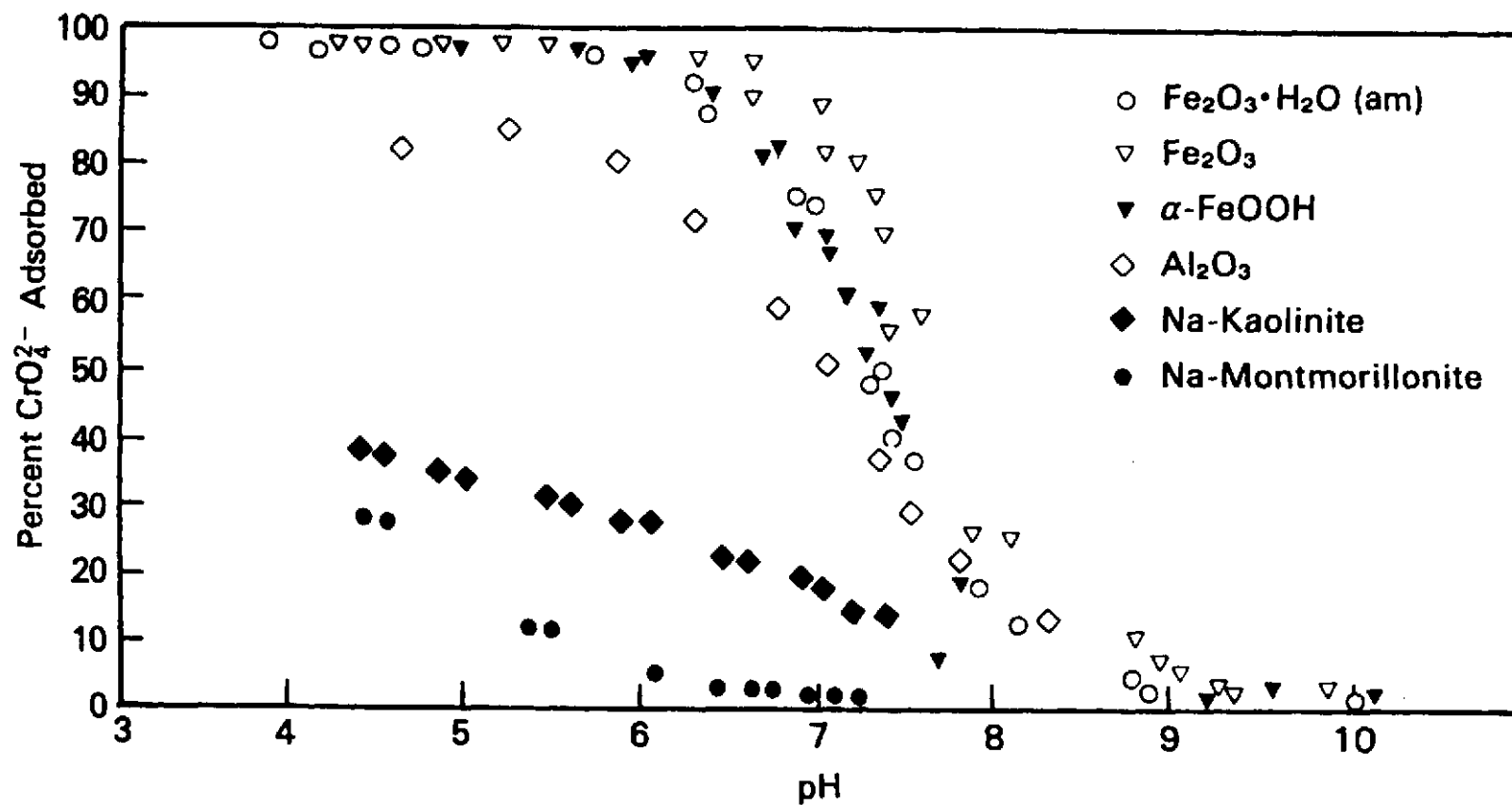
FIGURE 28. THEORETICAL Cr SPECIES IN MONITORING WELLS BASED ON Eh-pH MEASUREMENTS, MARCH, APRIL, AND AUG. 1990, INDUSTRI-PLEX SITE, WOBURN, MASSACHUSETTS
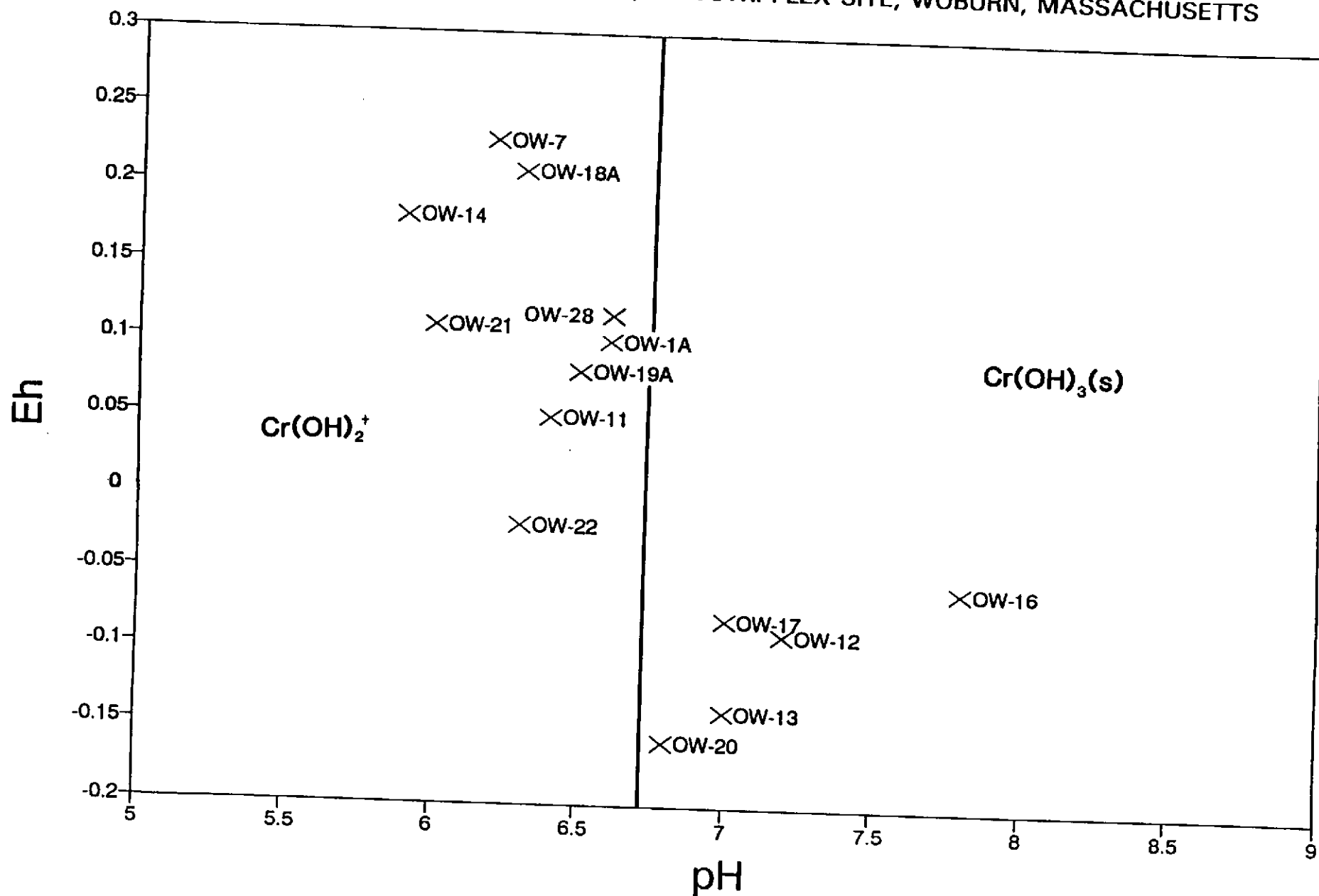
FIGURE 29. Eh-pH DIAGRAM FOR Cr AND Fe SPECIES. ΣFe = 1E-3, ΣCr = 1E-5. SCREENED AREA REPRESENTS Eh-pH MEASUREMENTS IN GROUNDWATER, MARCH, APRIL, AND AUG. 1990, INDUSTRI-PLEX SITE, WOBURN, MASSACHUSETTS
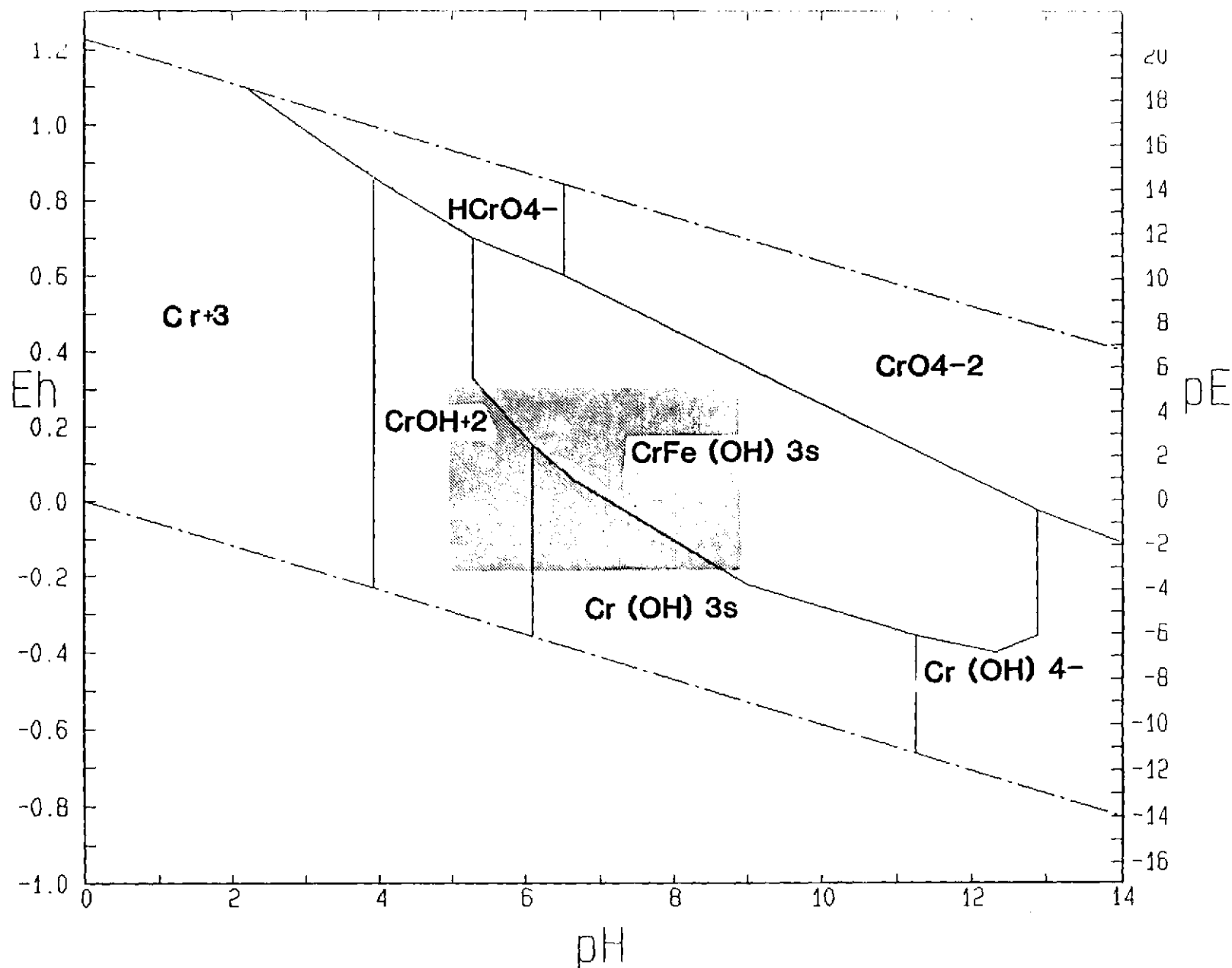
FIGURE 30. THEORETICAL Cr SPECIES IN MONITORING WELLS BASED ON Eh-pH MEASUREMENTS, MARCH, APRIL, AND AUG. 1990, INDUSTRI-PLEX SITE, WOBURN, MASSACHUSETTS. DASHED LINE REPRESENTS REGRESSION FIT THROUGH Eh AND pH DATA POINTS
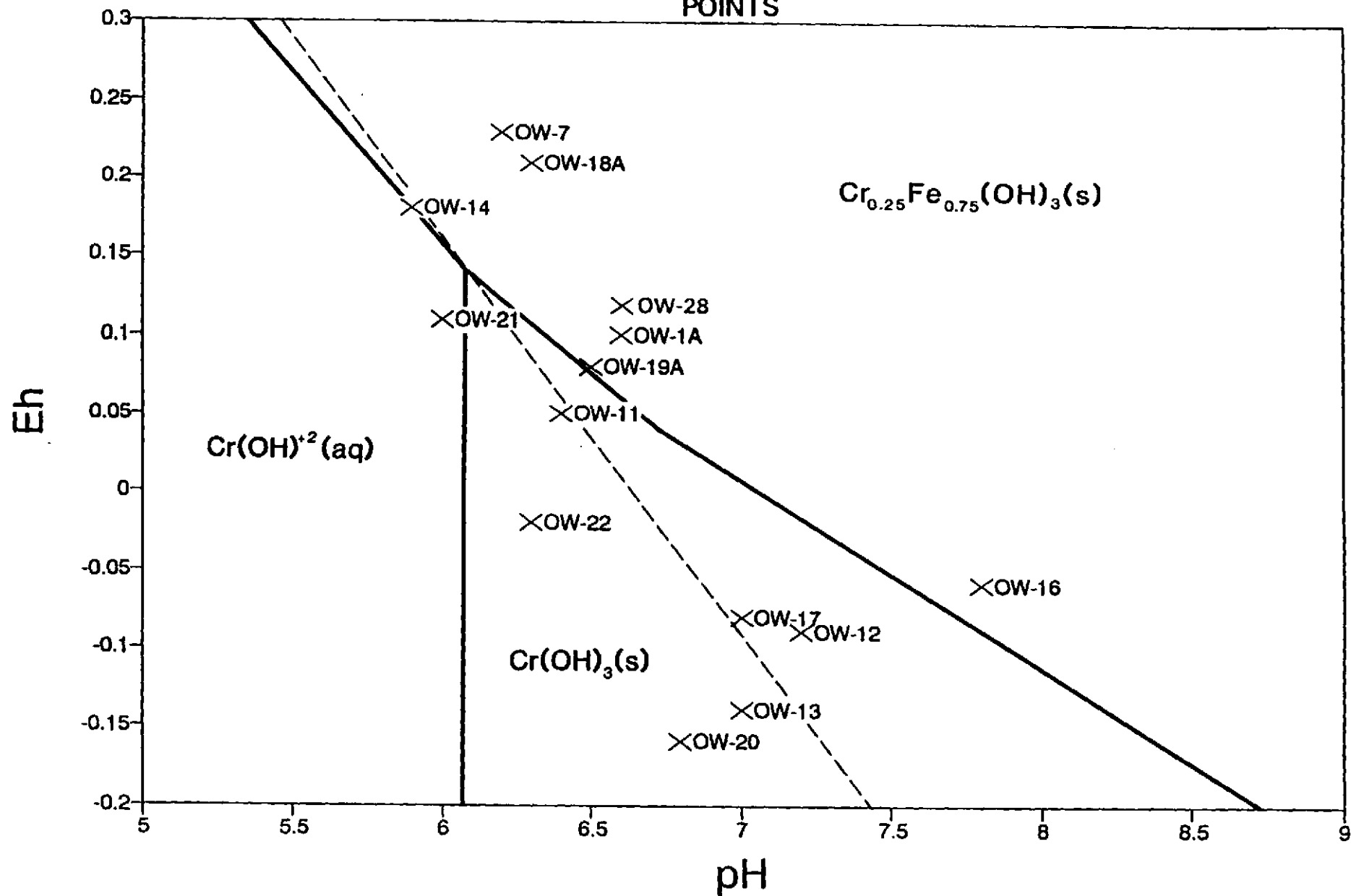
FIGURE 31. Eh-pH DIAGRAM FOR Hg SPECIES. ΣHg = 1E-3. SCREENED AREA REPRESENTS Eh-pH MEASUREMENTS IN GROUNDWATER, MARCH, APRIL, AND AUG. 1990, INDUSTRI-PLEX SITE, WOBURN, MASSACHUSETTS
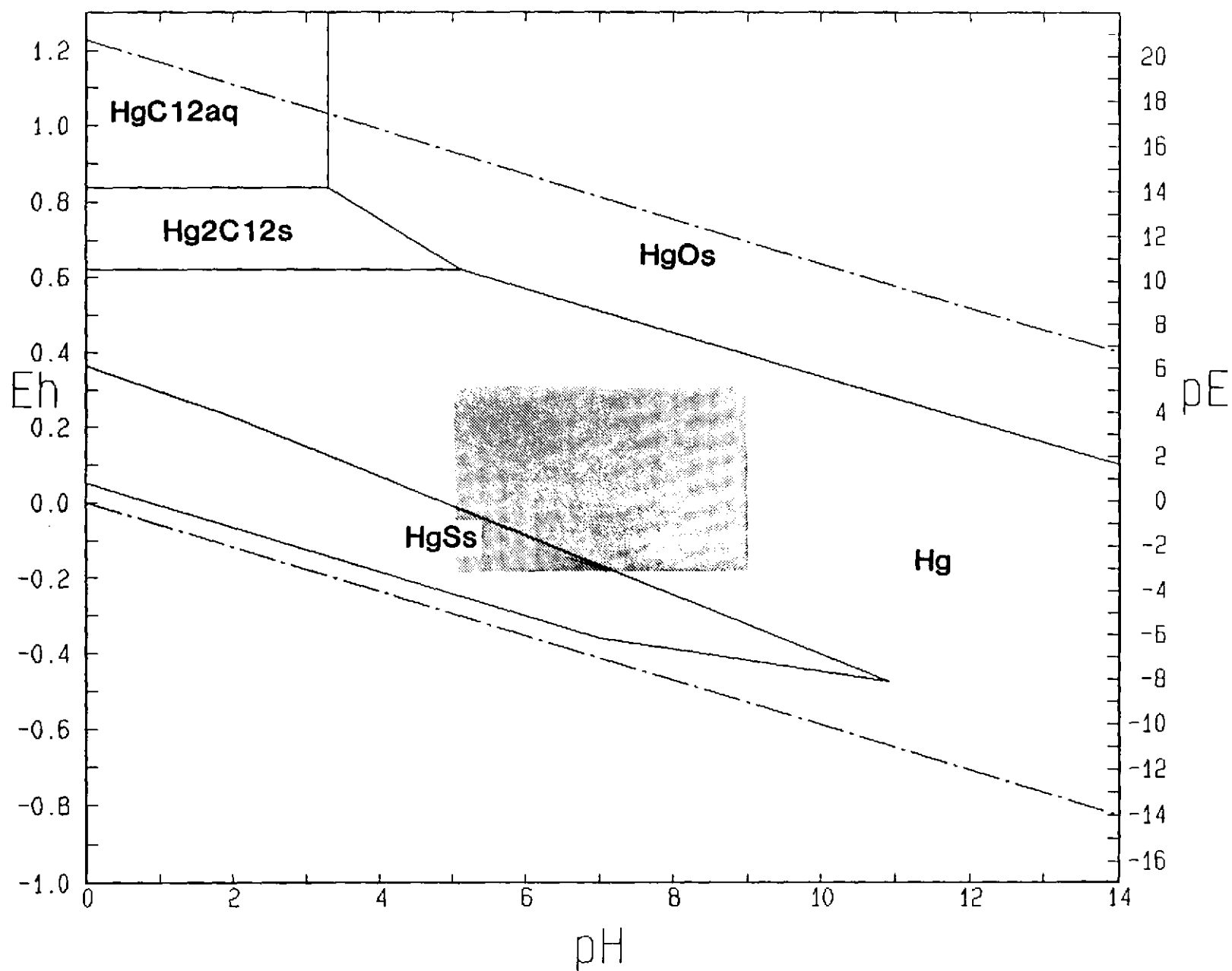
FIGURE 32. THEORETICAL Hg SPECIES IN MONITORING WELLS BASED ON Eh-pH MEASUREMENTS, MARCH, APRIL, AND AUG. 1990, INDUSTRI-PLEX SITE, WOBURN, MASSACHUSETTS
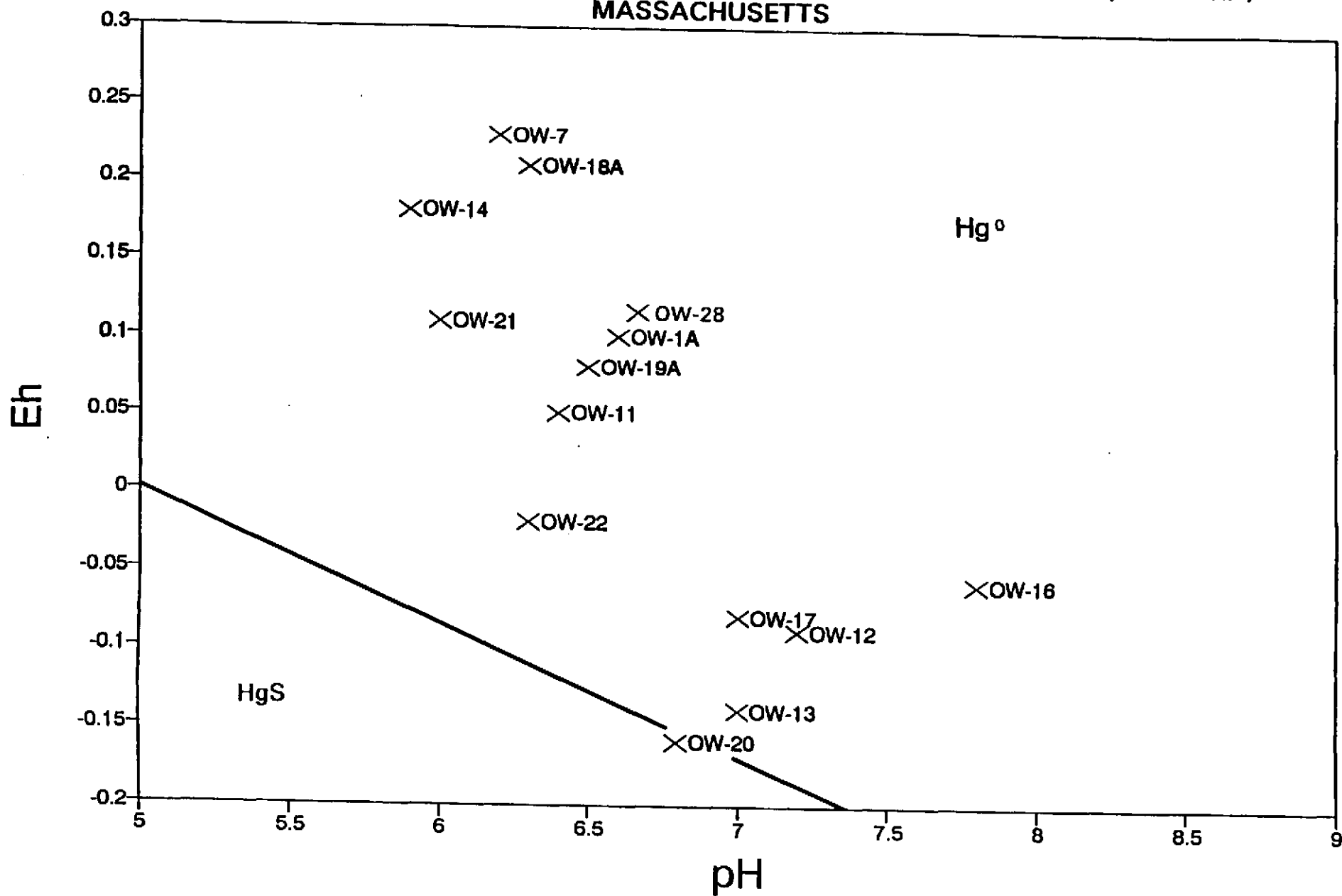
FIGURE 33. Eh-pH DIAGRAM FOR Pb SPECIES. SCREENED AREA REPRESENTS Eh-Ph MEASUREMENTS IN GROUNDWATER, MARCH, APRIL, AND AUG. 1990, INDUSTRI-PLEX SITE, WOBURN, MASSACHUSETTS

Map showing properties in the Woburn industrial area, including labeled parcels:

- N/F AERO REALTY TRUST
- N/F CHESTNUT HILL REALTY TRUST
- EAST-CENTRAL HIDE PILE
- N/F JOHN C. KOSTER
- N/F ATLANTIC AVENUE ASSOCIATES, INC.
- N/F CHESTNUT HILL REALTY TRUST
- N/F SUNDER K. AND HIRO K. GANGLANI
- N/F INDUSTRI-PLEX SITE INTERIM CUSTODIAL TRUST
- ATLANTIC AVENUE
- N/F WOBURN INDUSTRIAL ASSOCIATES, INC.
- N/F WINTER HILL STOREHOUSE, INC.
- N/F ATLANTIC AVENUE TRUST
- N/F NOORAERT REALTY TRUST
- COMMERCE WAY
- N/F INDUSTRI-PLEX SITE INTERIM CUSTODIAL TRUST
- N/F CITY OF WOBURN
- MASSACHUSETTS BAY TRANSPORTATION AUTHORITY
- SOUTH HIDE PILE
- N/F THE BOYD CORPORATION
- PHILLIPS POND
- HALLS BROOK HOLDING AREA
- N/F BOSTON EDISON COMPANY
- ABERJONA RIVER
- 74-10 commerce way

FIGURE 34. THEORETICAL Pb SPECIES IN MONITORING WELLS BASED ON Eh AND pH MEASUREMENTS, MARCH, APRIL, AND AUG. 1990, INDUSTRI-PLEX SITE, WOBURN, MASSACHUSETTS
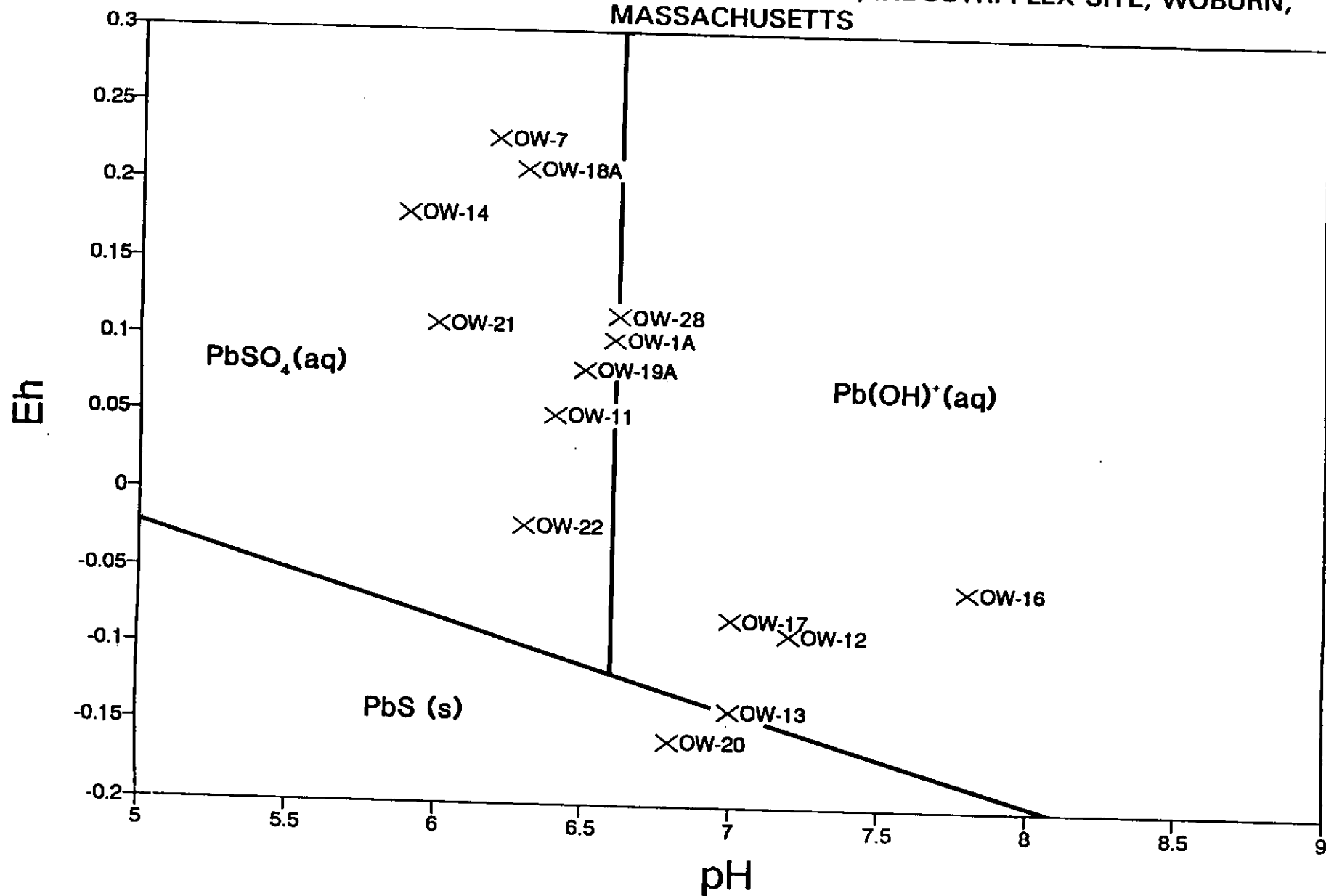
FIGURE 35. ADSORPTION OF ALKALINE EARTH, TRANSITION, AND HEAVY METAL CATIONS BY HYDROUS OXIDE GEL OF IRON (FROM KINNIBURGH ET AL. 1976)
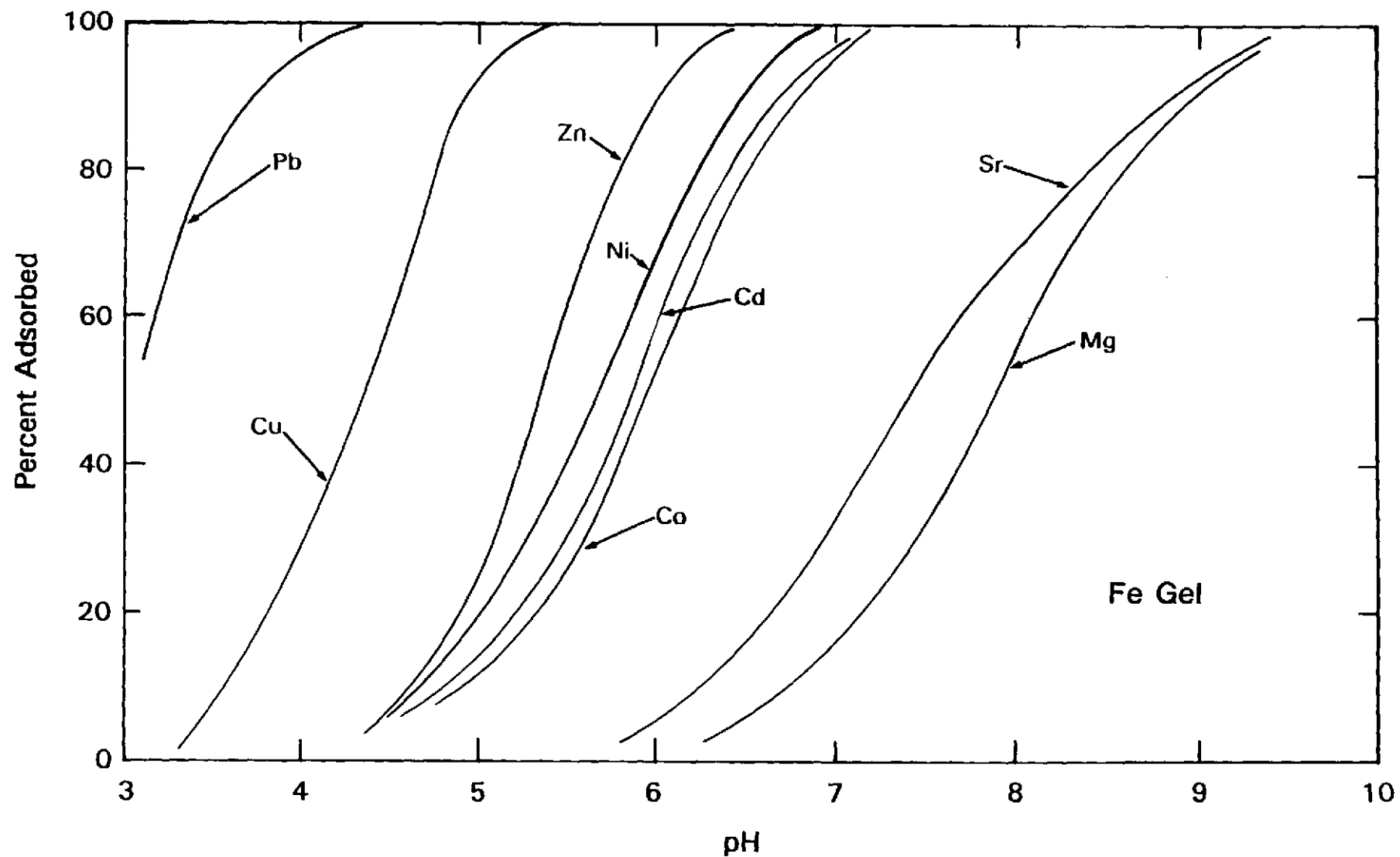
FIGURE 36. DISTRIBUTION OF ACETIC ACID COMPLEXES AS A FUNCTION OF pH
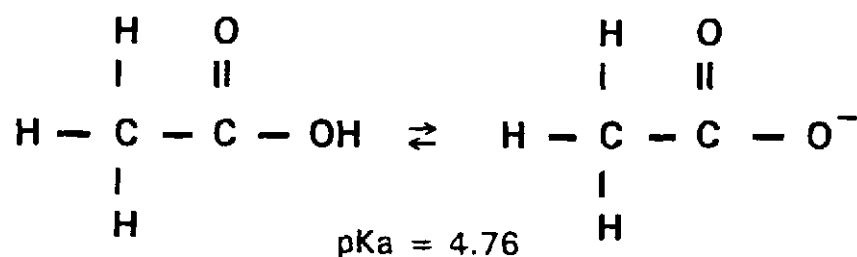
Acetic acid ⇌ Acetate

pKa = 4.76
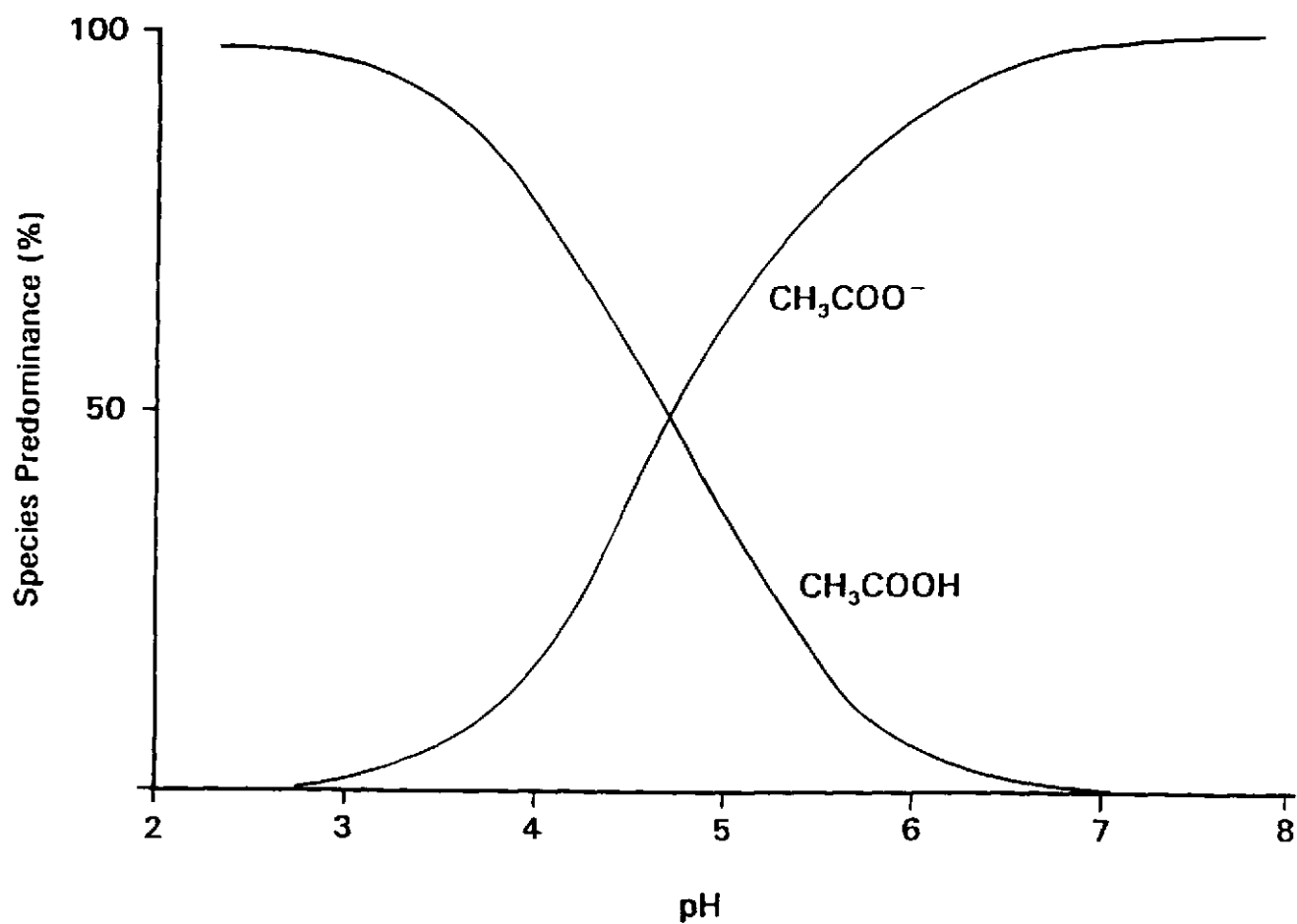
FIGURE 37. PROBABILITY DISTRIBUTION PLOT FOR ORIGINAL SOIL As CONCENTRATION DATA AND THE LOG TRANSFORMED EQUIVALENT (n = 822)

Original Data
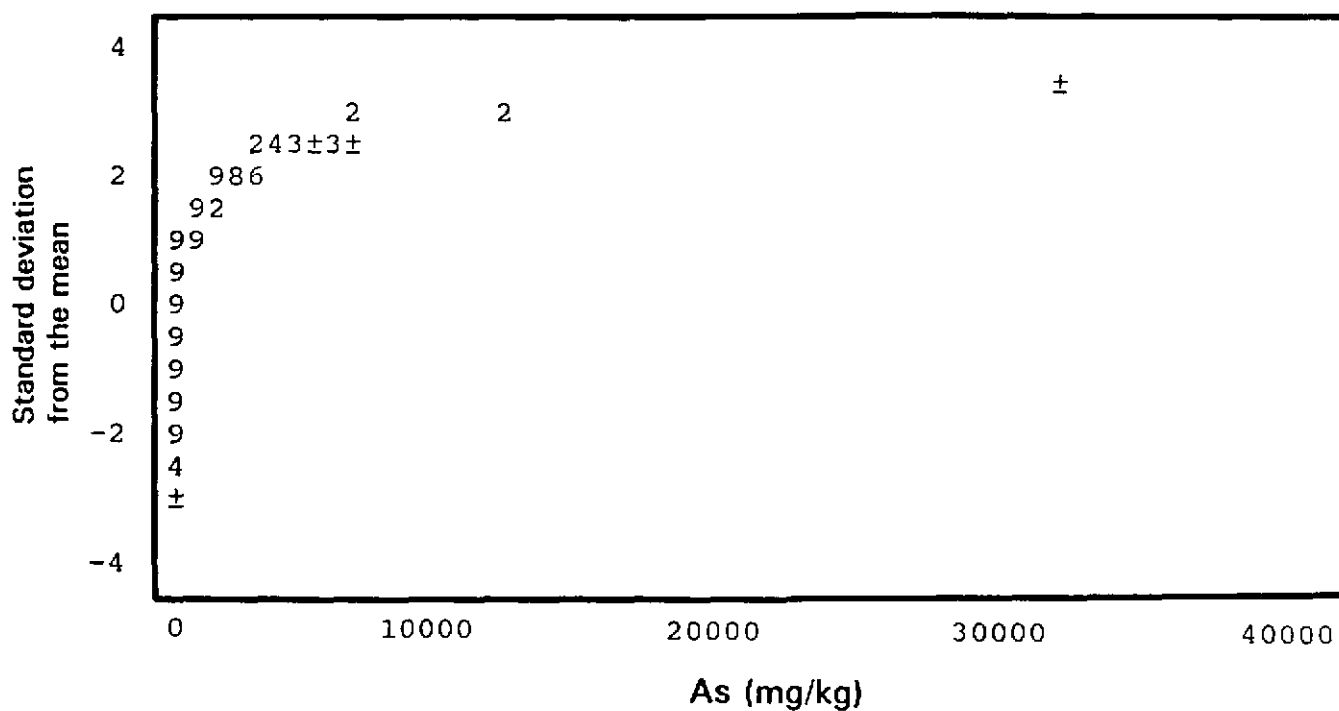
Transformed Data
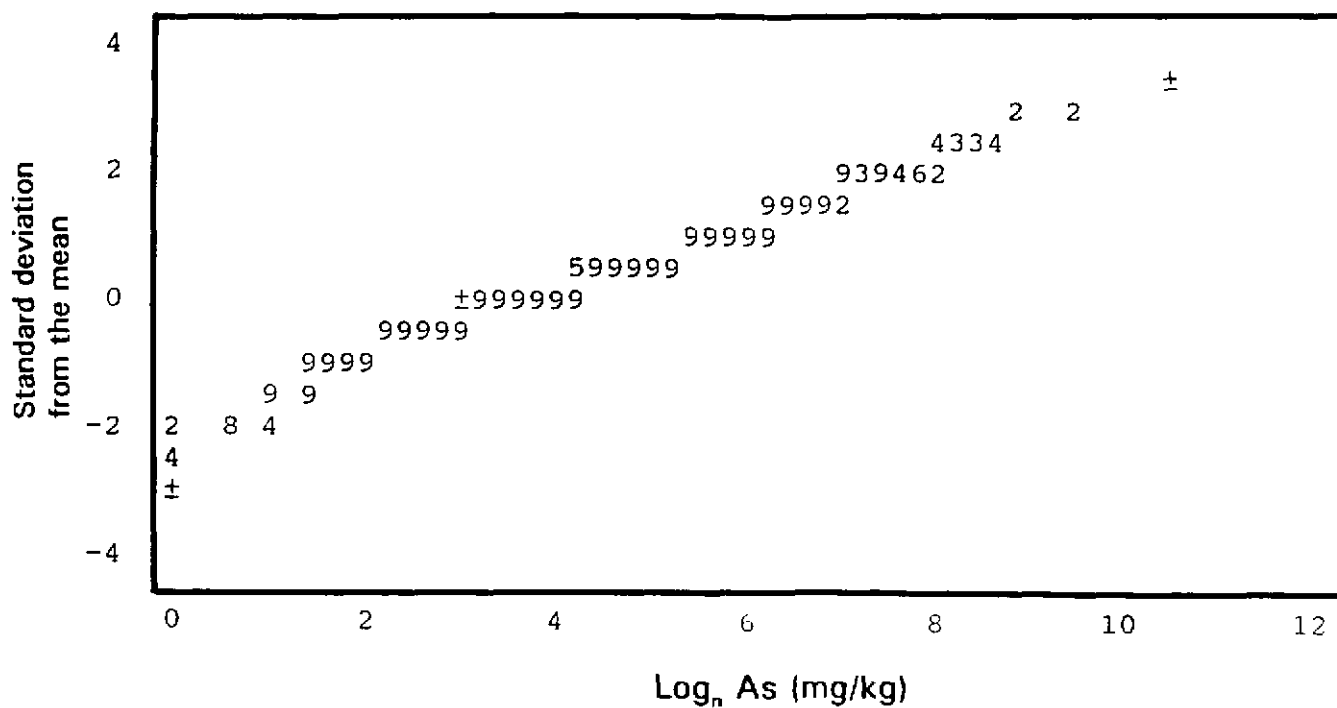
FIGURE 38. PROBABILITY DISTRIBUTION PLOT FOR ORIGINAL DISSOLVED Fe GROUNDWATER DATA AND THE LOG TRANSFORMED EQUIVALENT (n = 22)

Original Data
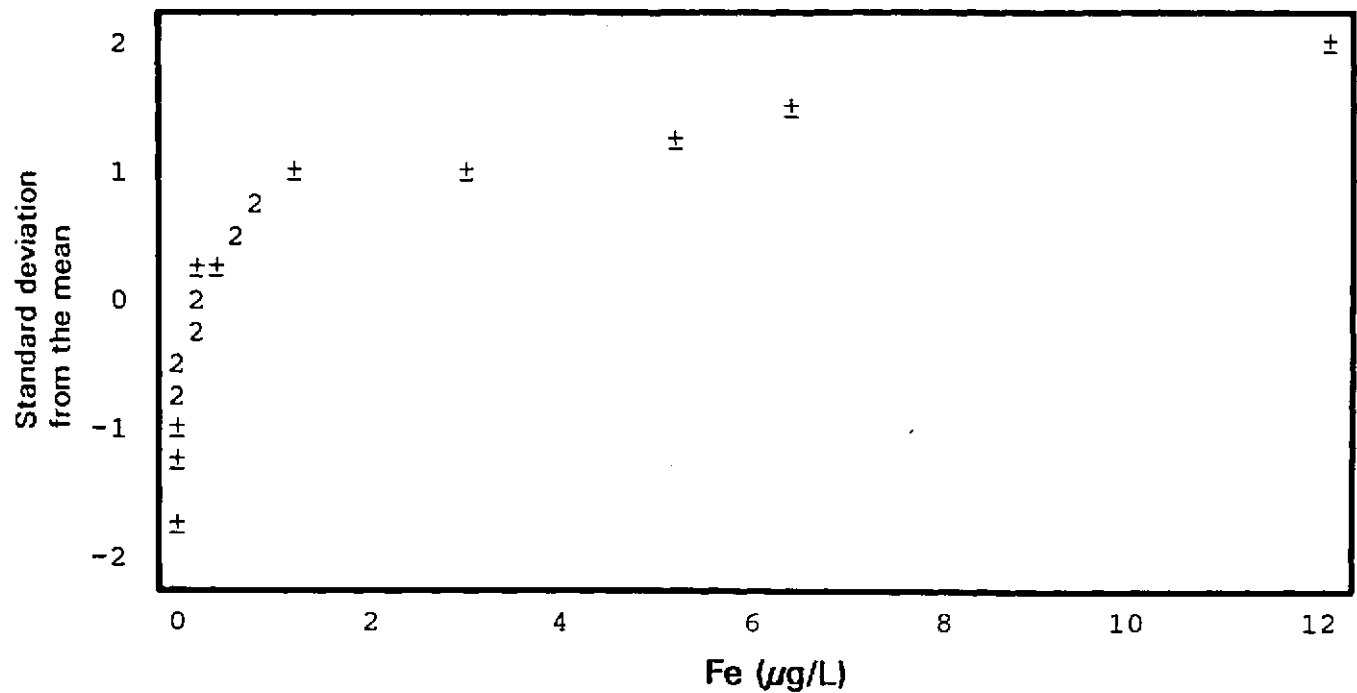
Transformed Data
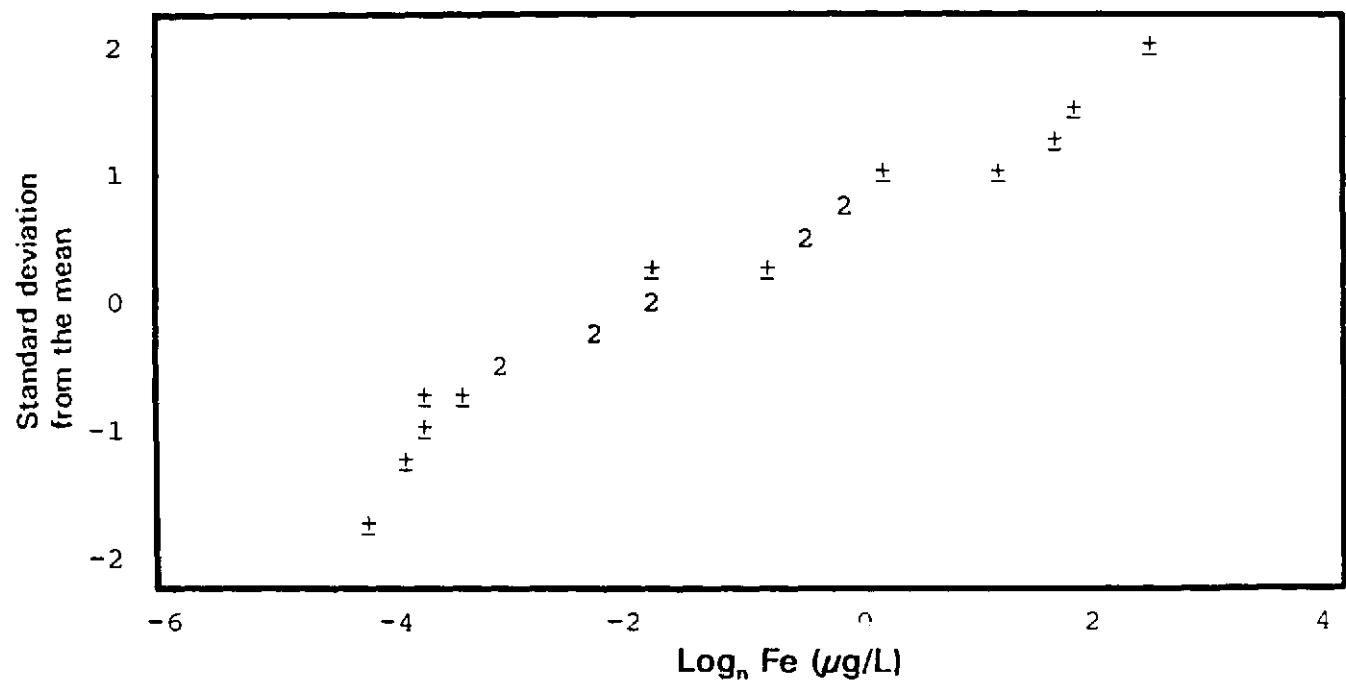
FIGURE 39. CLUSTER DIAGRAM DESCRIBING STATISTICAL MONITORING WELL GROUPINGS (COMPLETE LINKAGE METHOD) BASED ON THE LOG NORMALLY TRANSFORMED DATABASE FOR DISSOLVED ANALYTES FROM THE MARCH 1990 SAMPLING ROUND
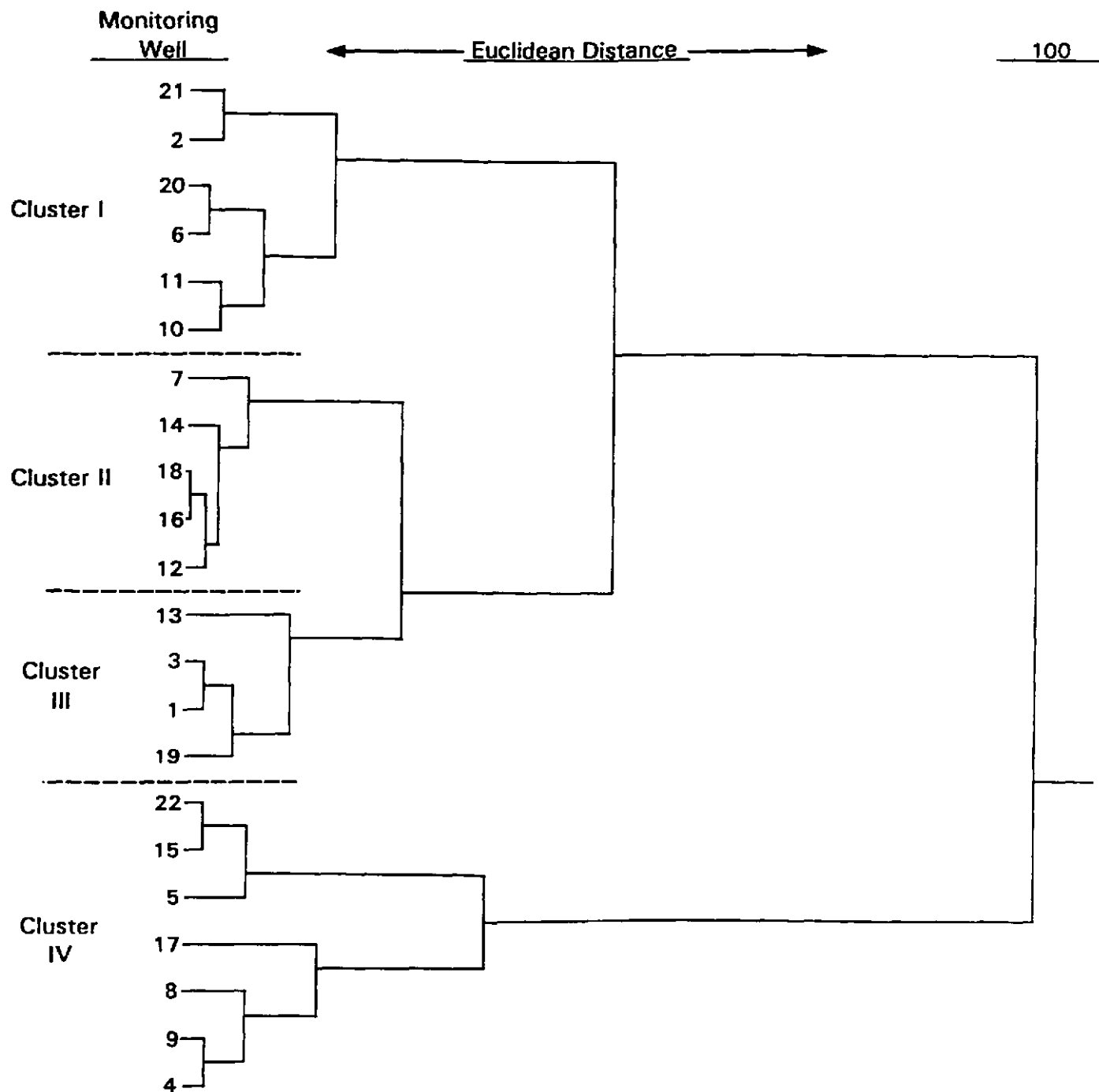
FIGURE 40: TRILINEAR PLOT (PIPER DIAGRAM) OF GROUNDWATERS, MARCH, APRIL, AND AUG. 1990, INDUSTRI-PLEX SITE, WOBURN, MASSACHUSETTS
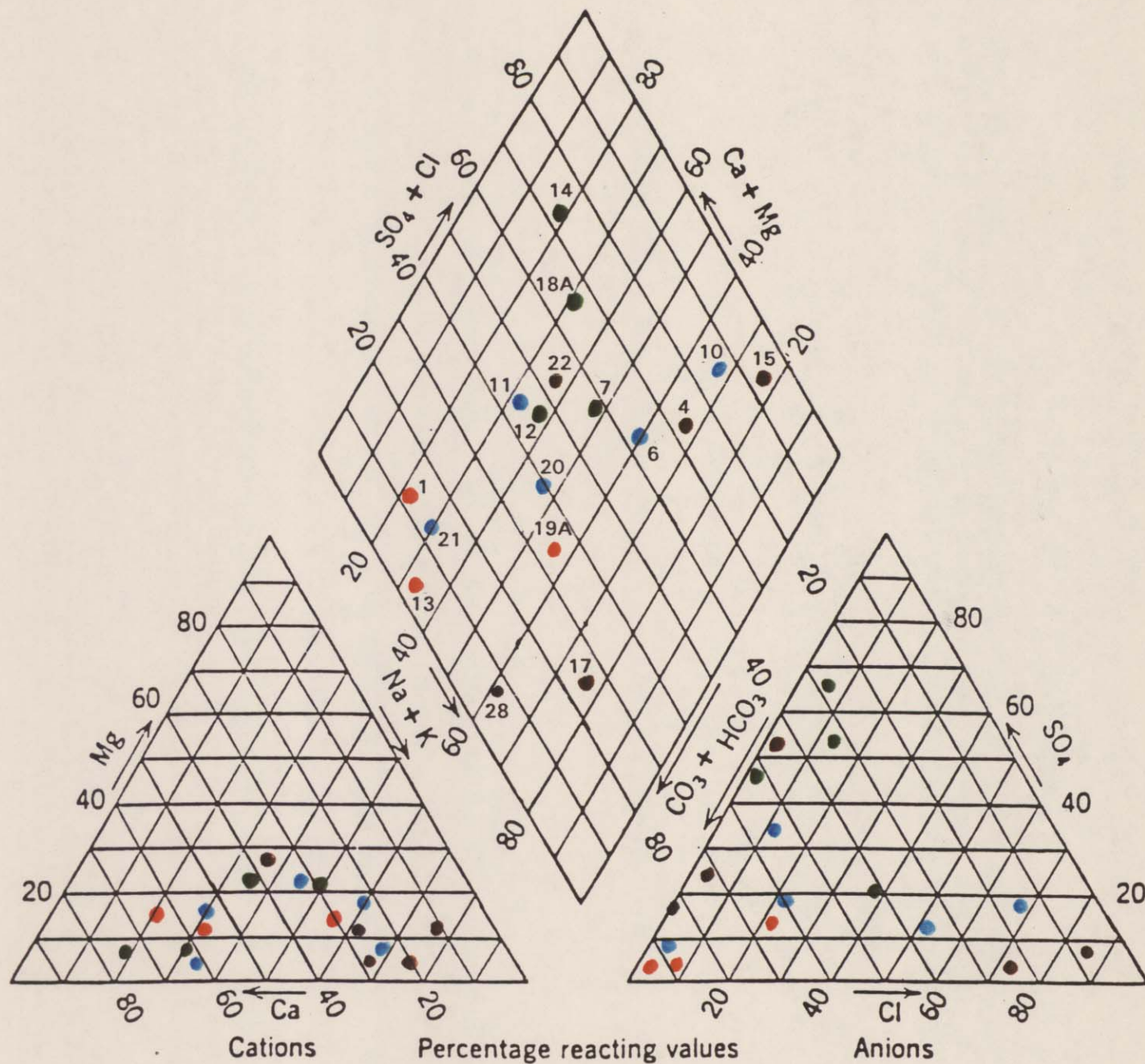
FIGURE 41. RELATIONSHIP BETWEEN pH/Eh AND As/COD ON TRANSFORMED SHALLOW GROUNDWATER DATA, MARCH 1990
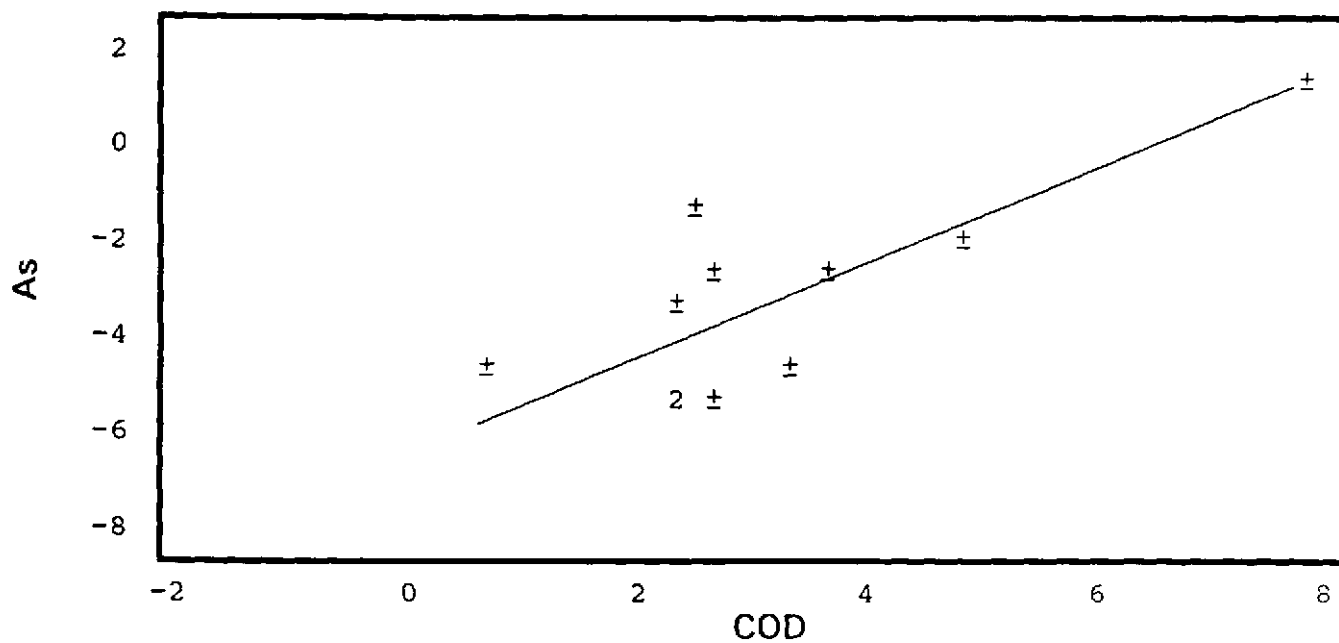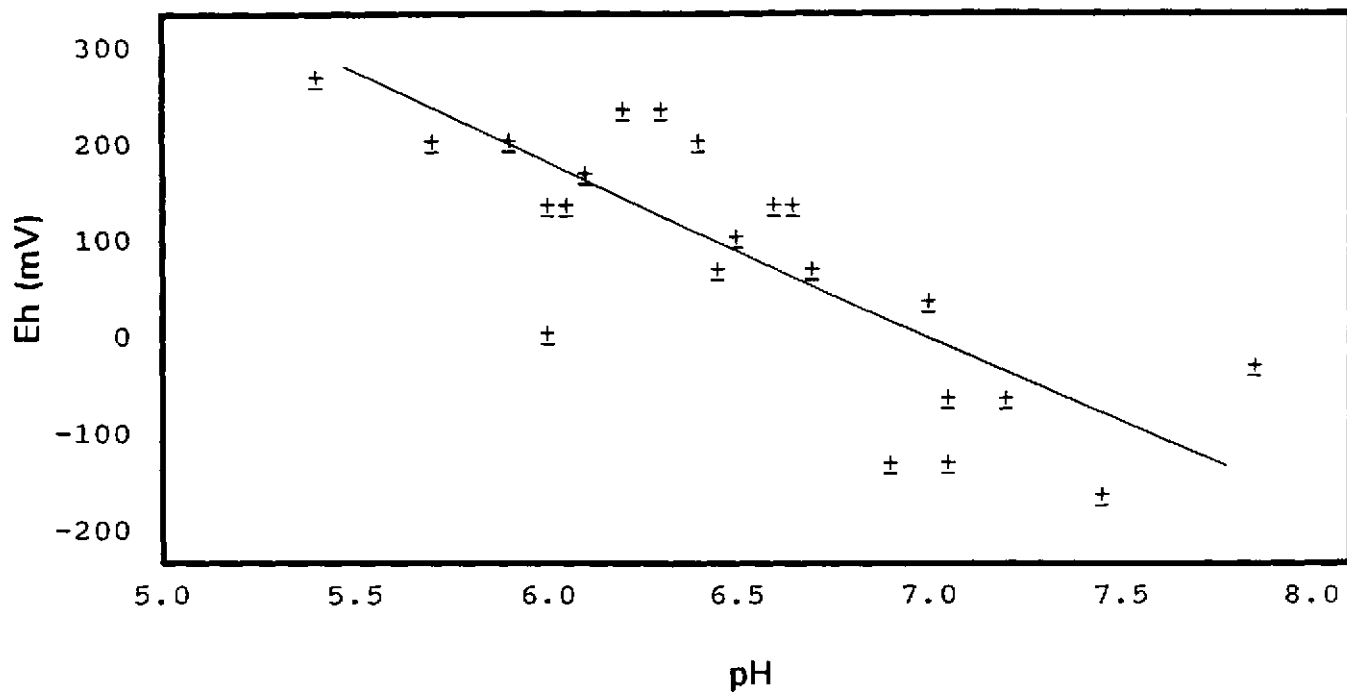
FIGURE 42. INFERRED SORPTION ISOTHERMS FOR As AND Zn IN ALLUVIAL GROUNDWATER AT THE INDUSTRI-PLEX SITE
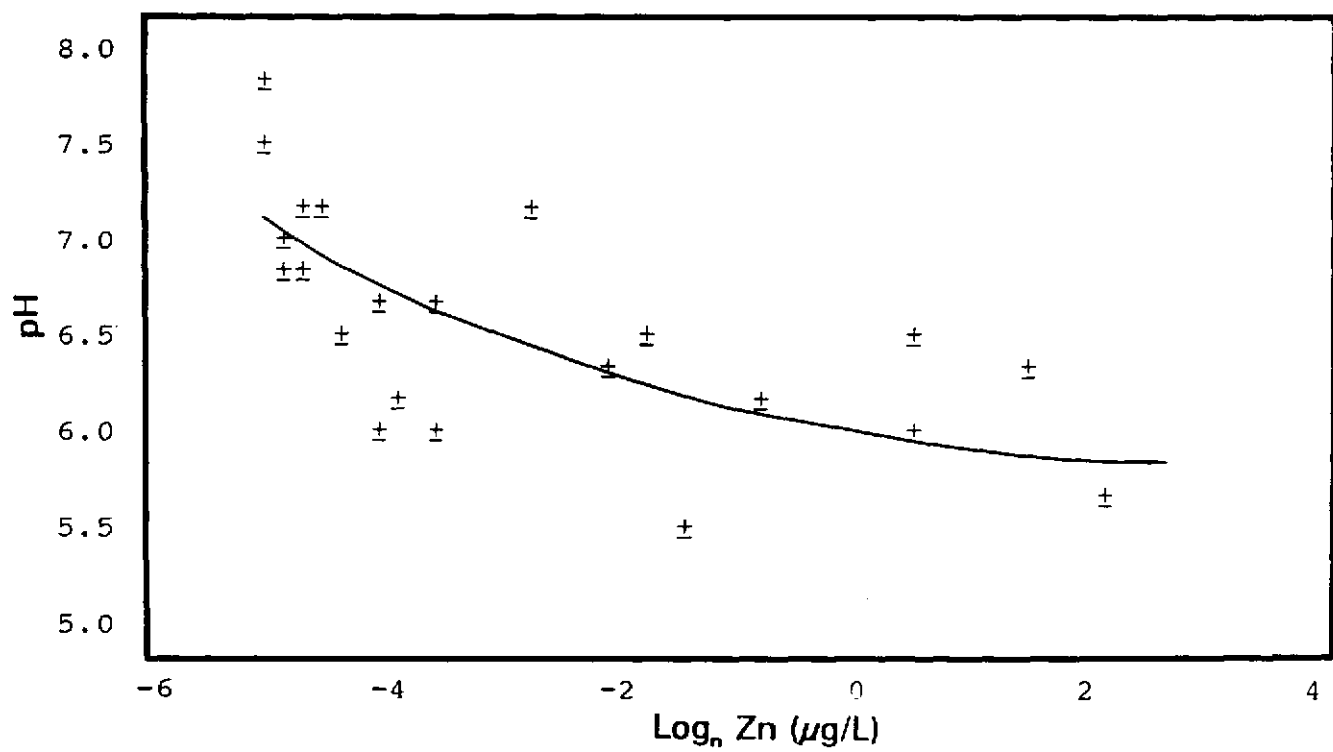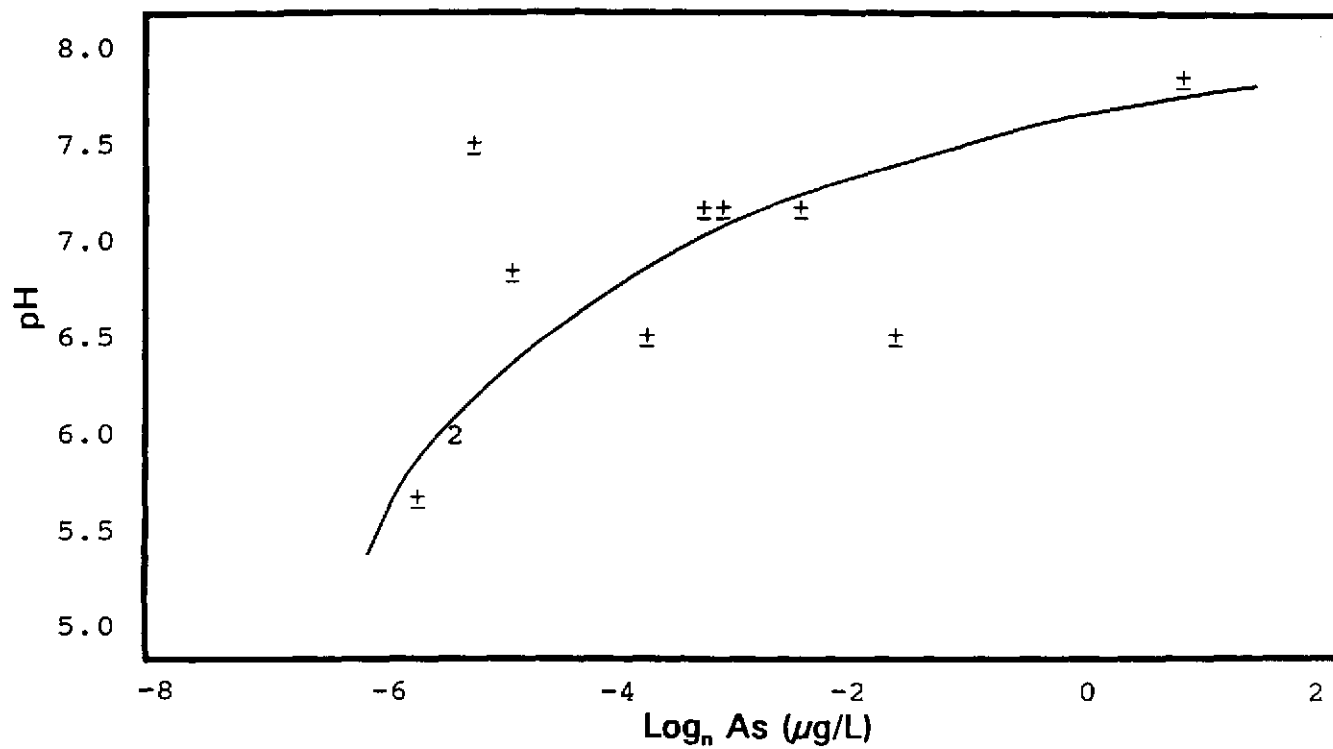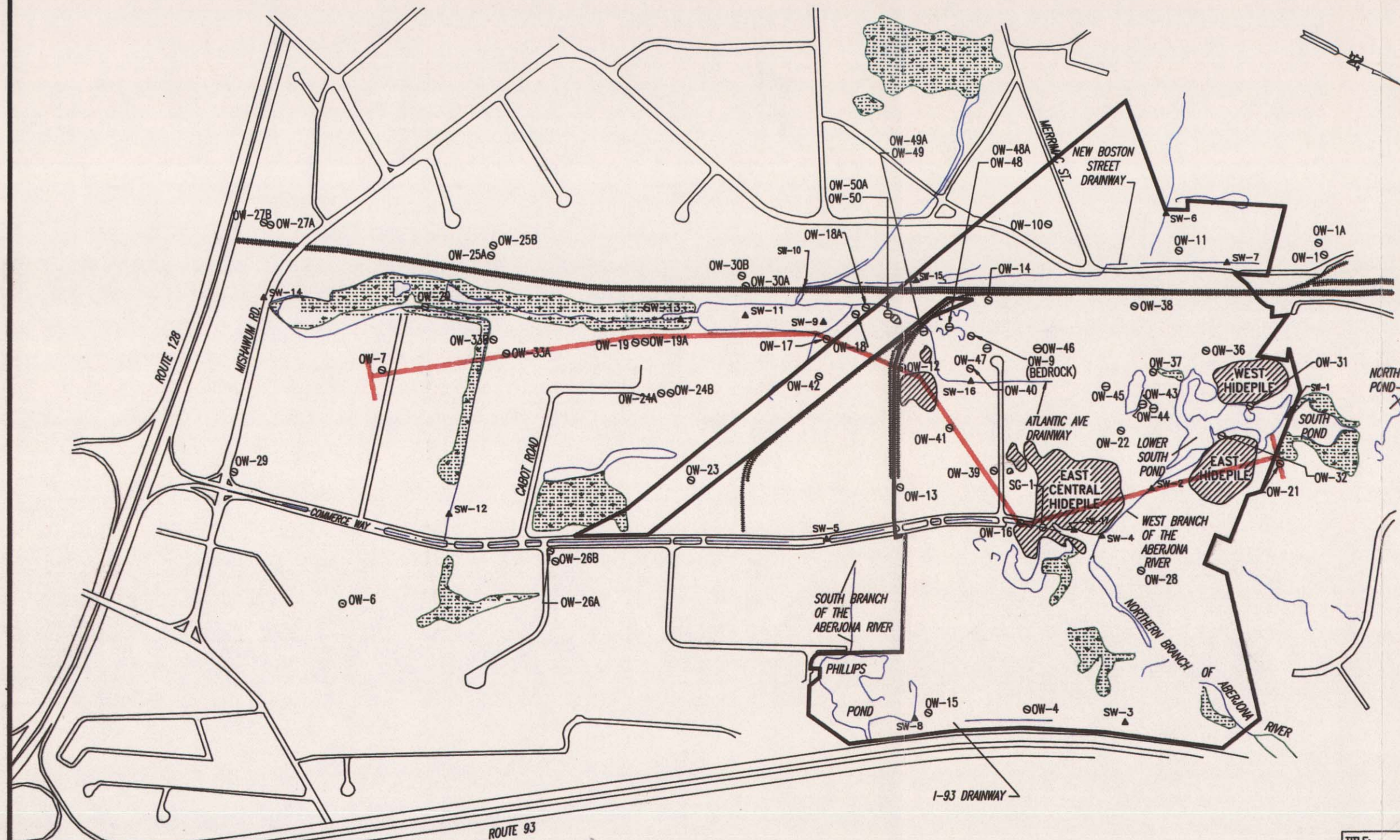
EXPLANATION

⌇⌇⌇⌇ CROSS-SECTION LINE

▦ WETLAND AREAS
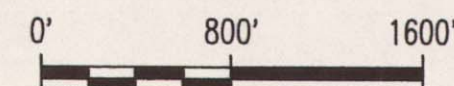
TITLE:

SATURATION INDEX
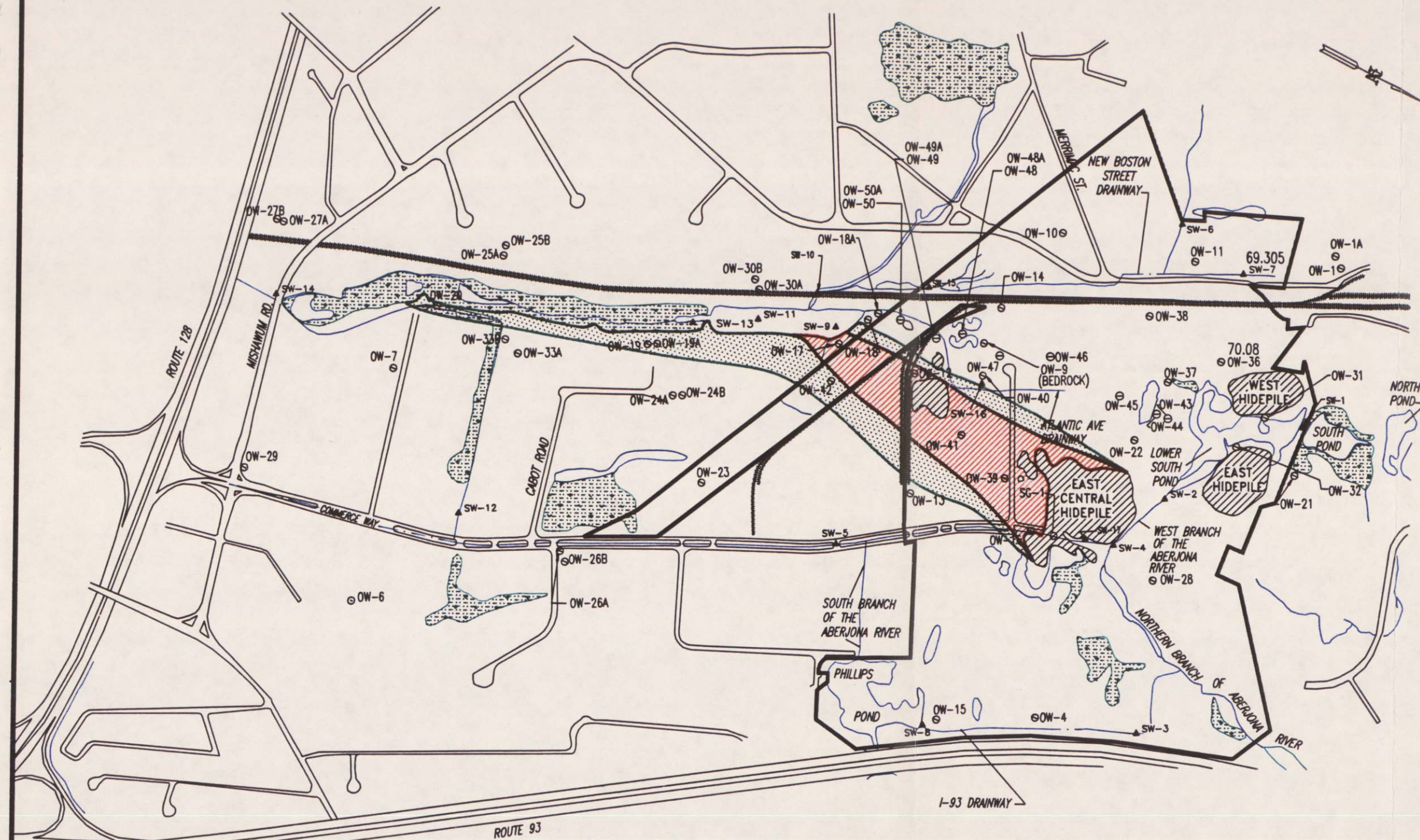CROSS-SECTION

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ROUX
ROUX ASSOCIATES, INC.
ENVIRONMENTAL CONSULTING
& MANAGEMENT

COMPILED BY:	J.Y.	DATE:	05/91	FIGURE
PREPARED BY:	R.P./C.L.	SCALE:	AS SHOWN	
PROJECT MANAGER:	T.B.	REVISION:	0	43
PROJECT NO.		06609D		

FIGURE 44. SATURATION INDICES FOR CALCITE AND GOETHITE ALONG THE CROSS SECTION IDENTIFIED IN FIGURE 43
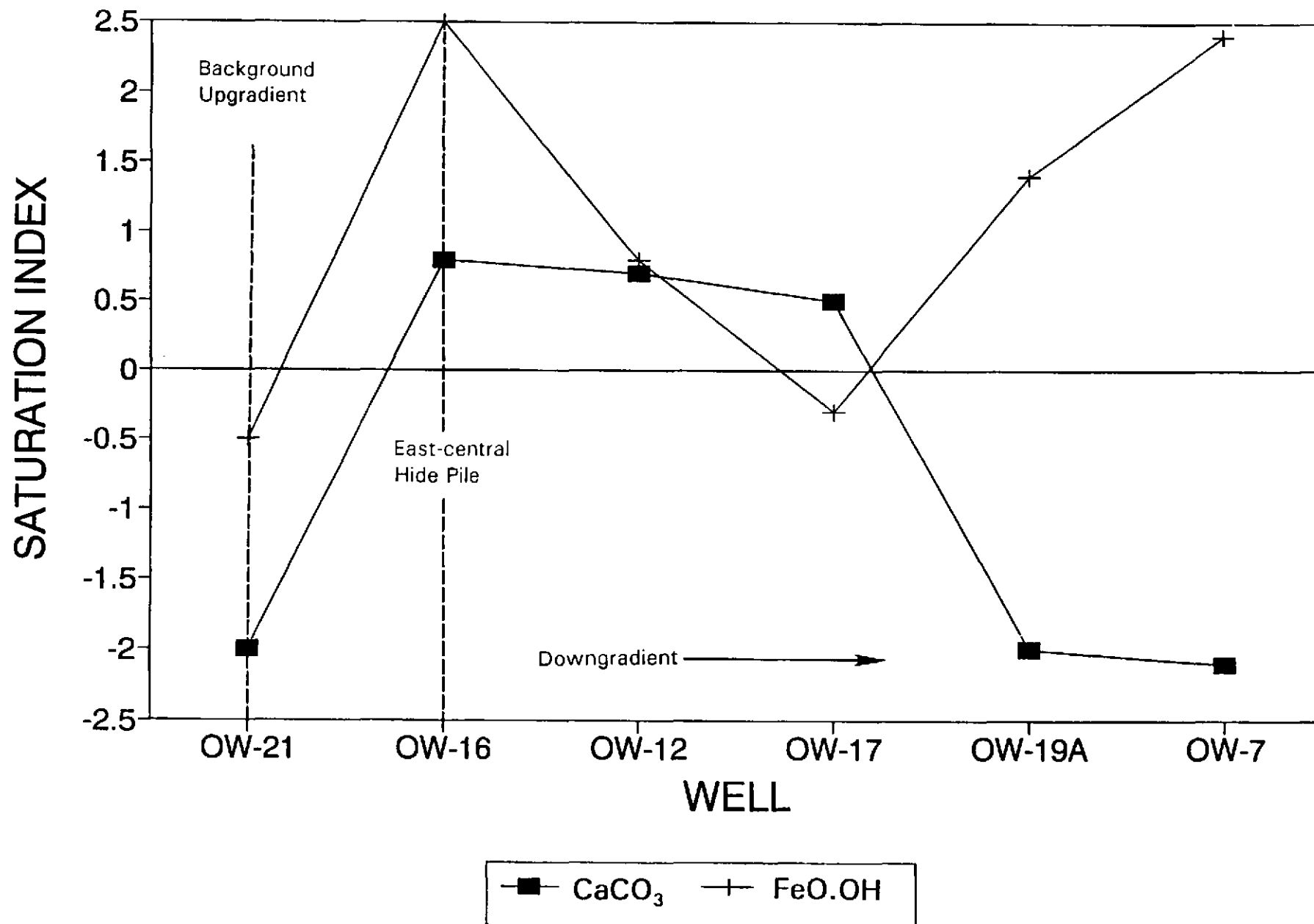
FIGURE 45. SATURATION INDICES FOR GYPSUM AND CHROME HYDROXIDES ALONG THE CROSS SECTION IDENTIFIED IN FIGURE 43

EXPLANATION

Eh VALUES

< 0 mV

0–100 mV

> 100 mV

WETLAND AREAS

NOTE: BASED ON GSIP DATA PROVIDED IN TABLE 3-7.

TITLE:

Eh OF GROUND WATER

Original includes color coding.

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ENVIRONMENTAL CONSULTING & MANAGEMENT

COMPILED BY:	J.Y.	DATE:	05/91	FIGURE
PREPARED BY:	R.P./C.L.	SCALE:	AS SHOWN	
PROJECT MANAGER:	T.B.	REVISION:	0	46
PROJECT NO.		06609D		
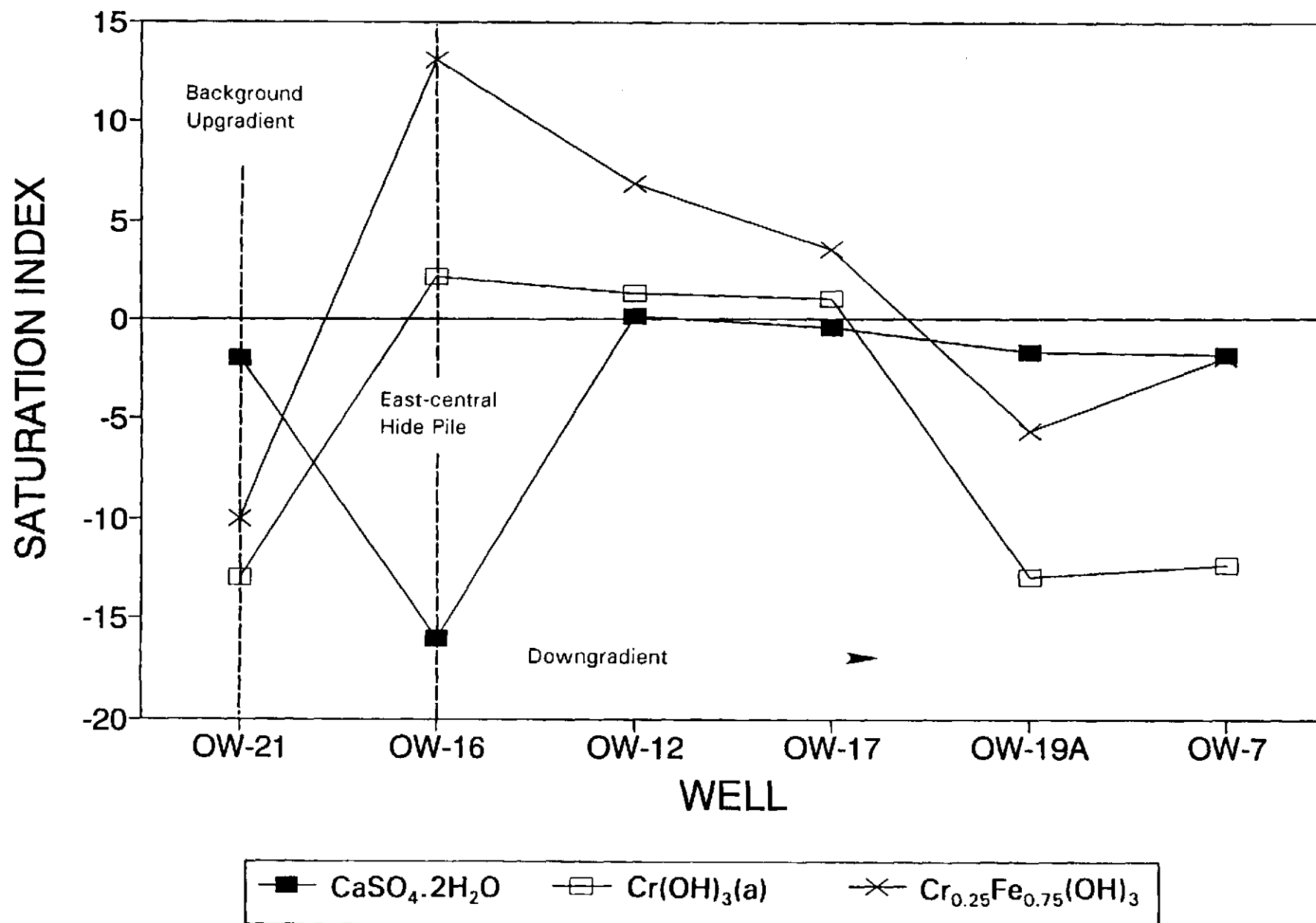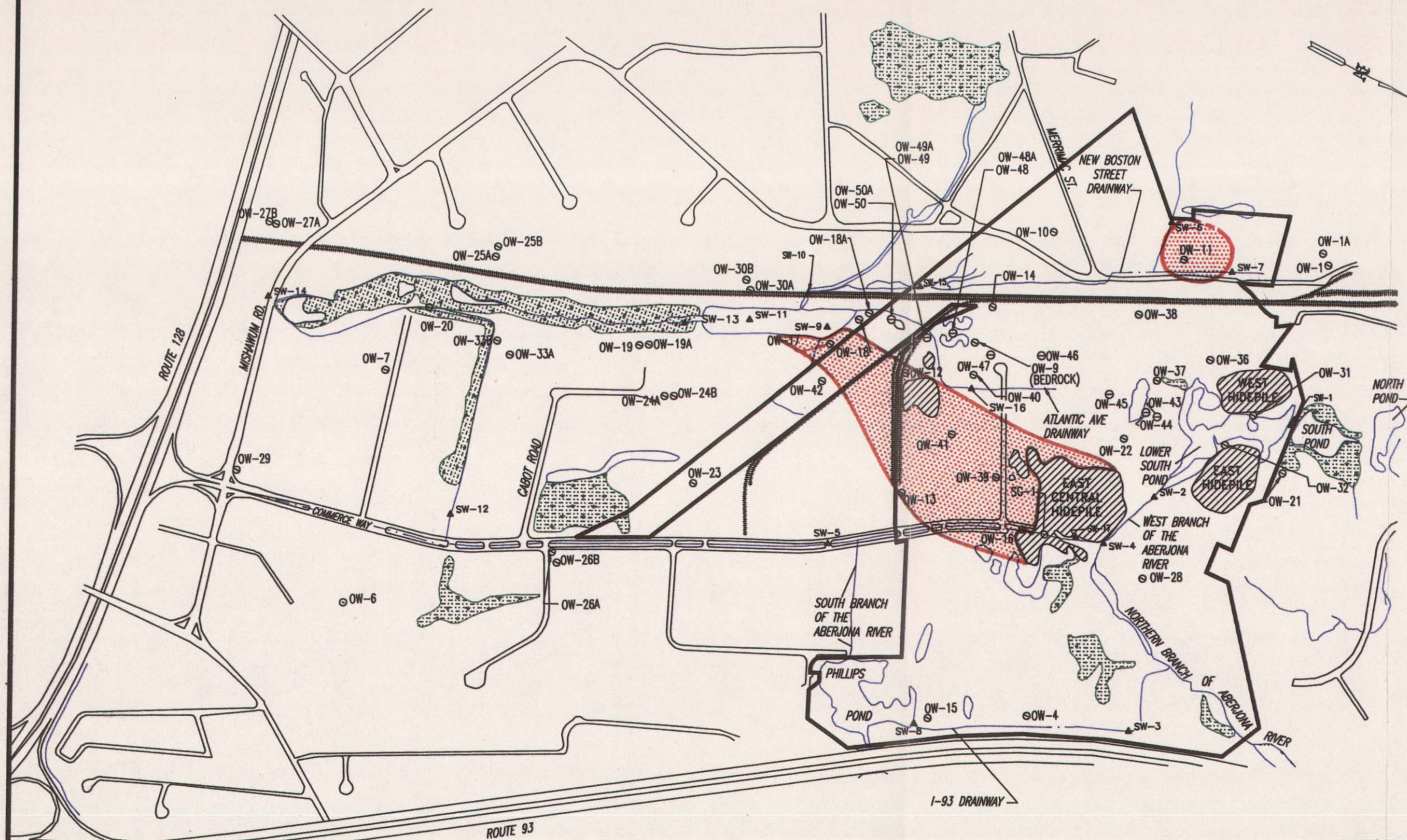
EXPLANATION

DISSOLVED OXYGEN

< 1 mg/L

> 1 mg/L

WETLAND AREAS

NOTE: BASED ON GSIP DATA PROVIDED IN APPENDIX B.

TITLE:

CONCENTRATION OF
DISSOLVED OXYGEN
IN GROUND WATER

Original includes color coding.

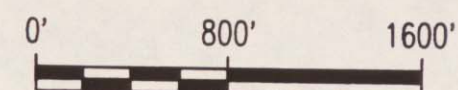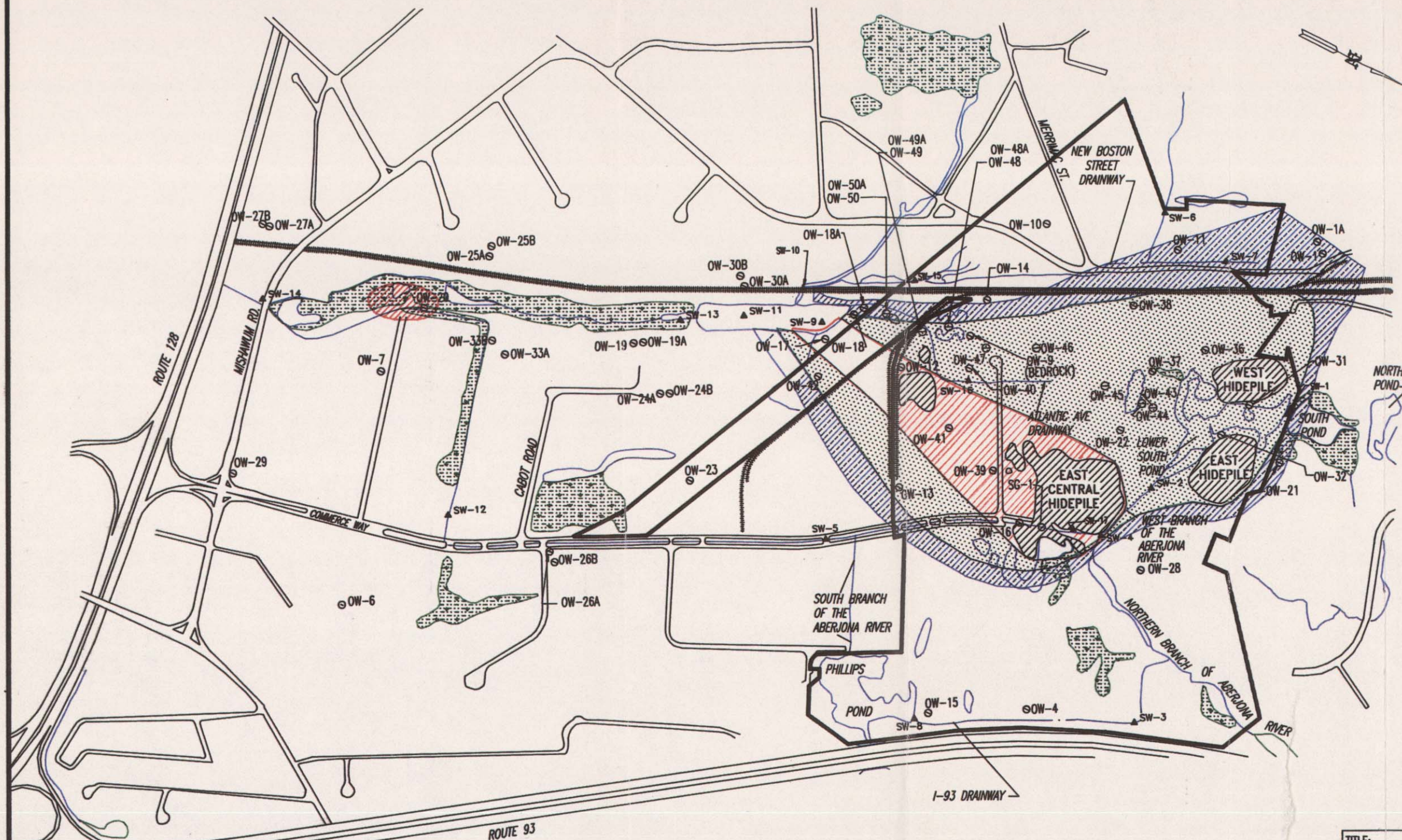PREPARED FOR:

INDUSTRI-PLEX REMEDIAL TRUST

ROUX
ROUX ASSOCIATES, INC.
ENVIRONMENTAL CONSULTING
& MANAGEMENT

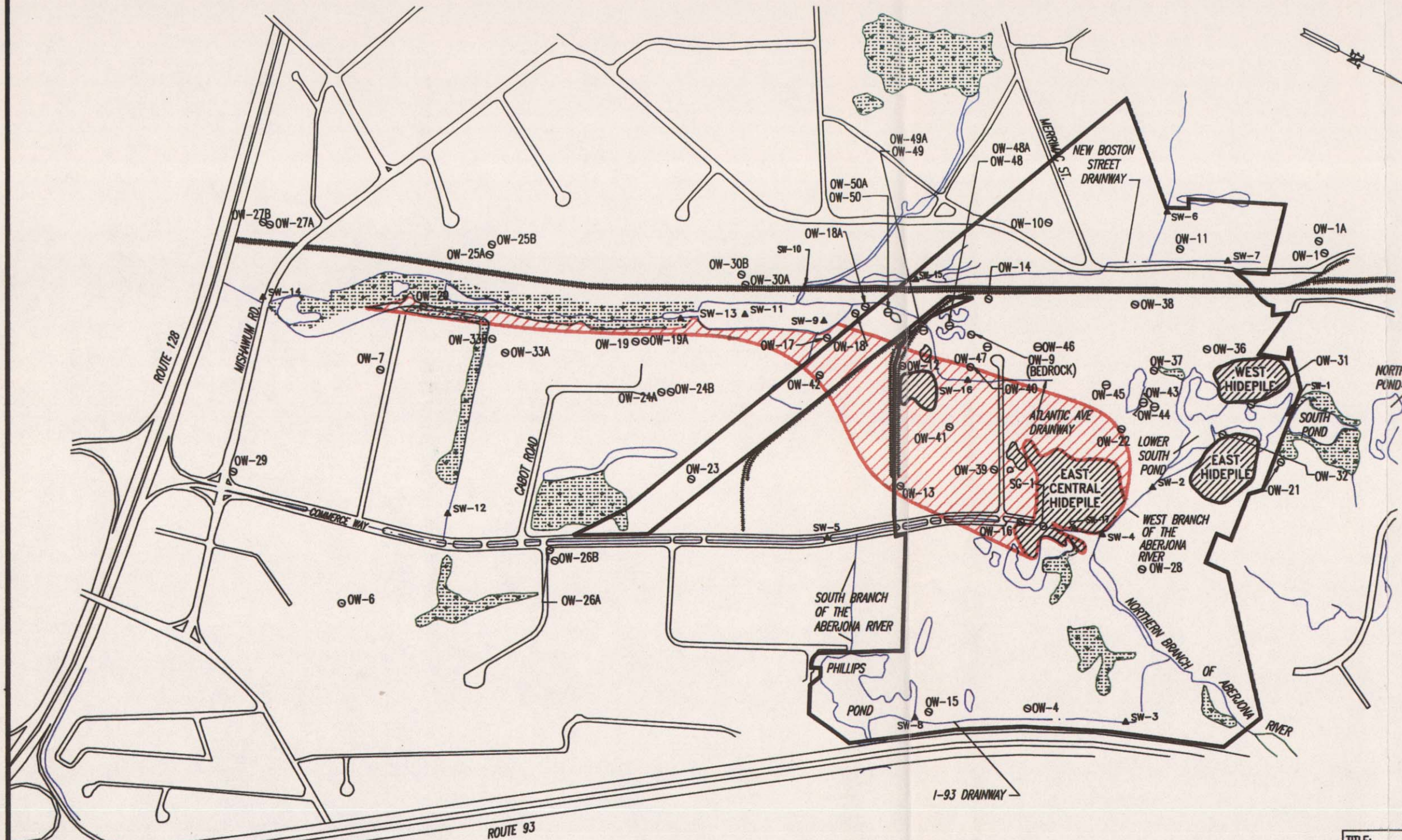| COMPILED BY: | J.Y. | DATE: | 05/91 | FIGURE |
PREPARED BY:	R.P./C.L.	SCALE:	AS SHOWN	
PROJECT MANAGER:	T.B.	REVISION:	0	47
PROJECT NO.		06609D		

0'   800'   1600'
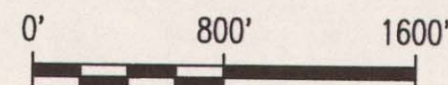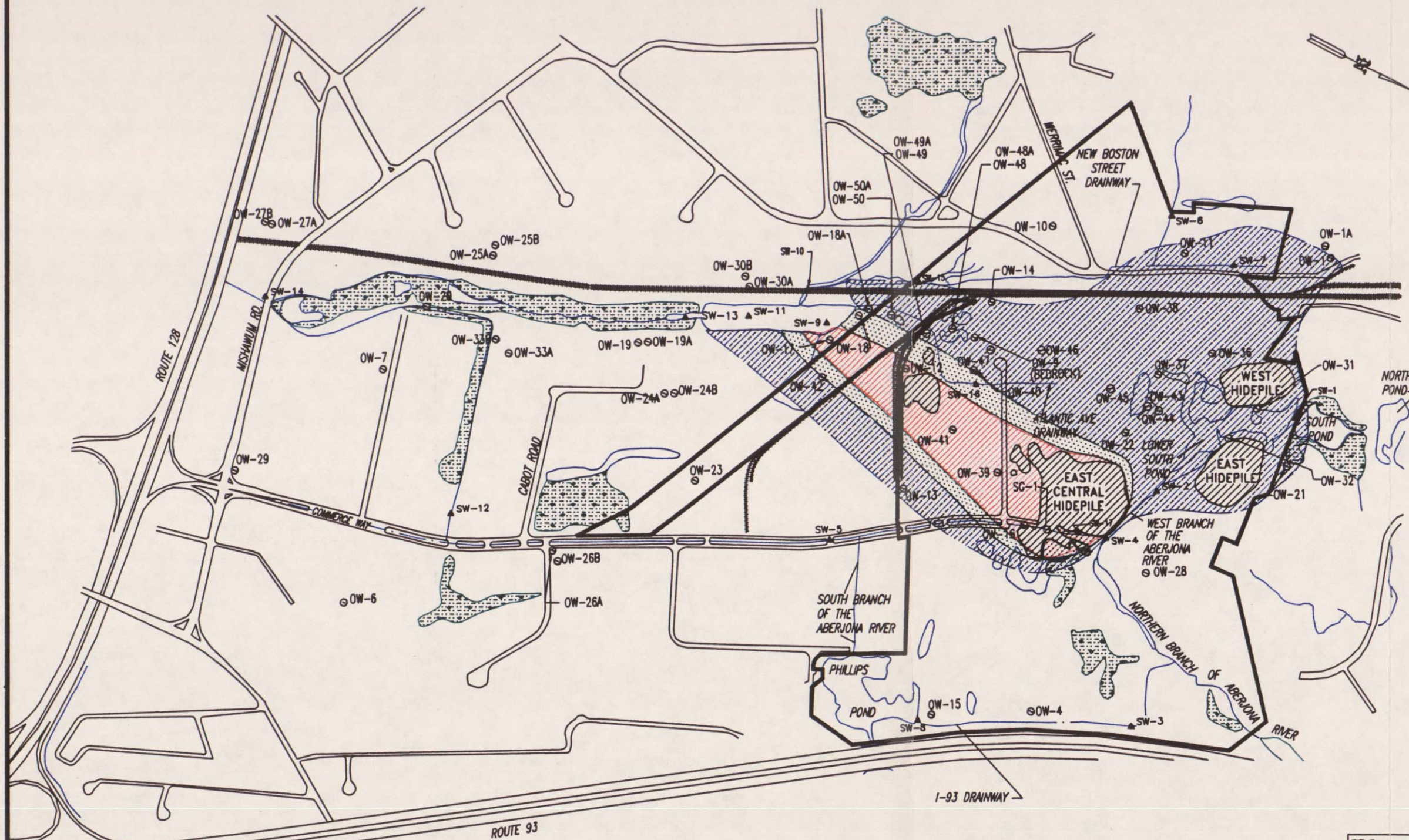
EXPLANATION

CHEMICAL OXYGEN DEMAND

(hatched red)	> 250 mg/L
(dotted)	100–250 mg/L
(hatched blue)	25–100 mg/L
(white)	< 25 mg/L
(grid)	WETLAND AREAS

NOTE: BASED ON GSIP DATA PROVIDED IN APPENDIX C

TITLE:

CHEMICAL OXYGEN
DEMAND
IN GROUND WATER

Original includes color coding.

PREPARED FOR:

INDUSTRI–PLEX REMEDIAL TRUST

0'   800'   1600'

ROUX
ROUX ASSOCIATES, INC.
ENVIRONMENTAL CONSULTING
& MANAGEMENT

COMPILED BY:	J.Y.	DATE:	05/91	FIGURE
PREPARED BY:	R.P./C.L.	SCALE:	AS SHOWN	48
PROJECT MANAGER:	T.B.	REVISION:	0	
PROJECT NO.	06609D			
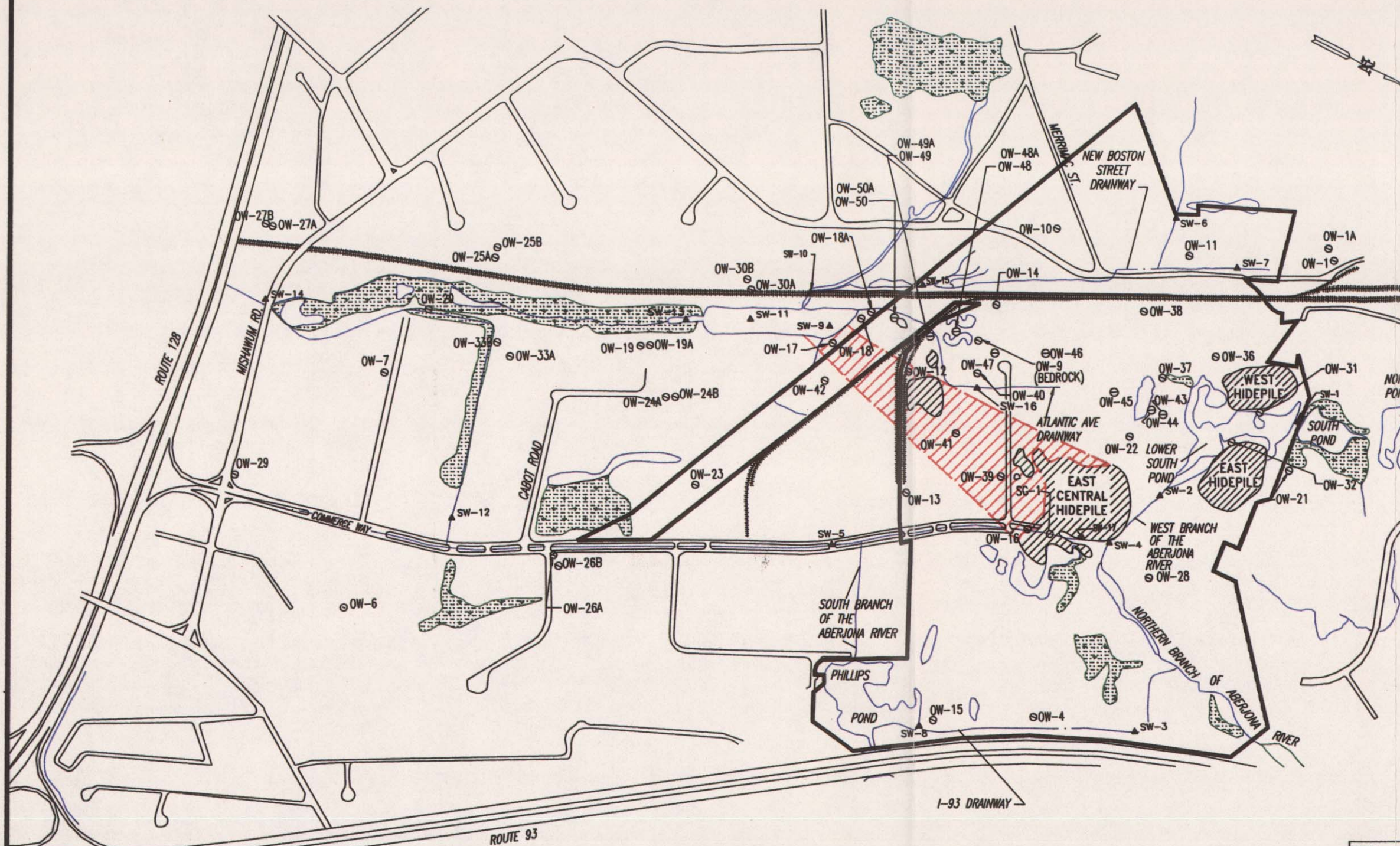
EXPLANATION

TOTAL ORGANIC CARBON

> 50 mg/L

WETLAND AREAS

NOTE: BASED ON GSIP DATA PROVIDED IN APPENDIX C

TITLE:

CONCENTRATION OF
TOTAL ORGANIC CARBON
IN GROUND WATER

Original includes color coding.

PREPARED FOR:

INDUSTRI-PLEX REMEDIAL TRUST

ROUX	COMPILED BY:	J.Y.	DATE:	05/91	FIGURE
ROUX ASSOCIATES, INC.	PREPARED BY:	R.P./C.L.	SCALE:	AS SHOWN	
ENVIRONMENTAL CONSULTING & MANAGEMENT	PROJECT MANAGER:	T.B.	REVISION:	0	49
	PROJECT NO.		06609D		

EXPLANATION

CONCENTRATION OF CHLORIDE

(red hatch)	> 100 mg/L
(stipple)	40–100 mg/L
(white)	< 40 mg/L
(crosshatch)	WETLAND AREAS

NOTE: BASED ON GSIP DATA PROVIDED IN APPENDIX C

TITLE:

CONCENTRATION OF
CHLORIDE
IN GROUND WATER

Original includes color coding.

PREPARED FOR:

INDUSTRI—PLEX REMEDIAL TRUST

ROUX
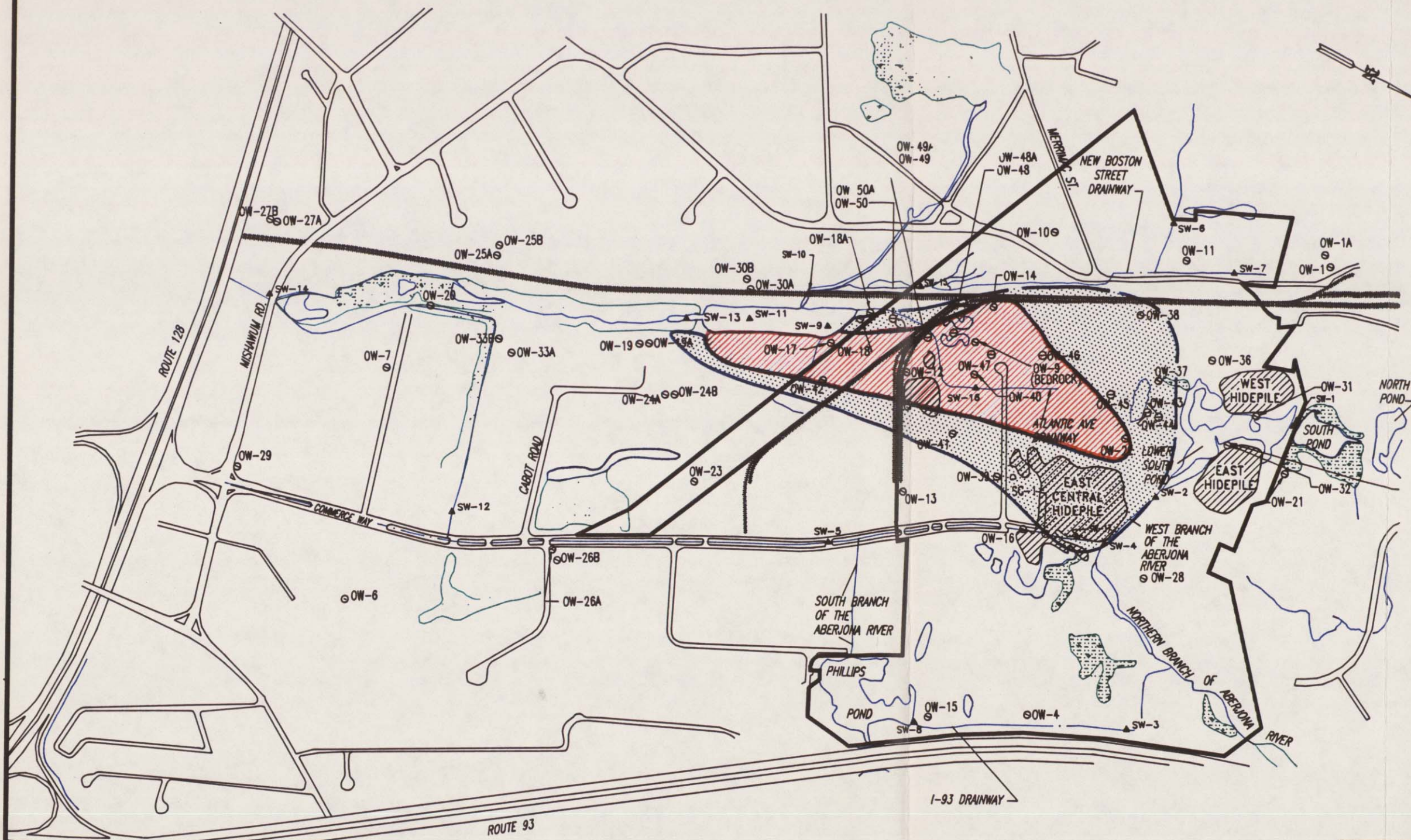
ROUX ASSOCIATES, INC.
ENVIRONMENTAL CONSULTING

COMPILED BY:	J.Y.	DATE:	05/91	FIGURE
PREPARED BY:	R.P./C.L.	SCALE:	AS SHOWN	
PROJECT MANAGER:	T.B.	REVISION:	0	50

0'   800'   1600'

EXPLANATION

ALKALINITY

> 1000 mg/L

100-1000 mg/L

50-100 mg/L

< 50 mg/L

WETLAND AREAS

NOTE: BASED ON GSIP DATA PROVIDED IN APPENDIX C
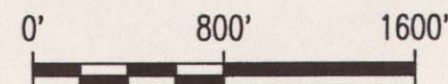
TITLE:

DISTRIBUTION OF ALKALINITY
(AS HCO$_3^-$)
IN GROUND WATER

Original includes color coding.

PREPARED FOR:

INDUSTRI-PLEX REMEDIAL TRUST

ROUX
ROUX ASSOCIATES, INC.
ENVIRONMENTAL CONSULTING
& MANAGEMENT

COMPILED BY:	J.Y.	DATE:	05/91	FIGURE
PREPARED BY:	R.P./C.L.	SCALE:	AS SHOWN	51
PROJECT MANAGER:	T.B.	REVISION:	0	
PROJECT NO.		06609D		

0'   800'   1600'

EXPLANATION

▨ As Ⅲ

☐ As Ⅴ

▦ WETLAND AREAS

NOTE: BASED ON GSIP DATA PROVIDED IN TABLE 3-7

TITLE:

Eh-ph CONDITIONS
CONDUCIVE TO
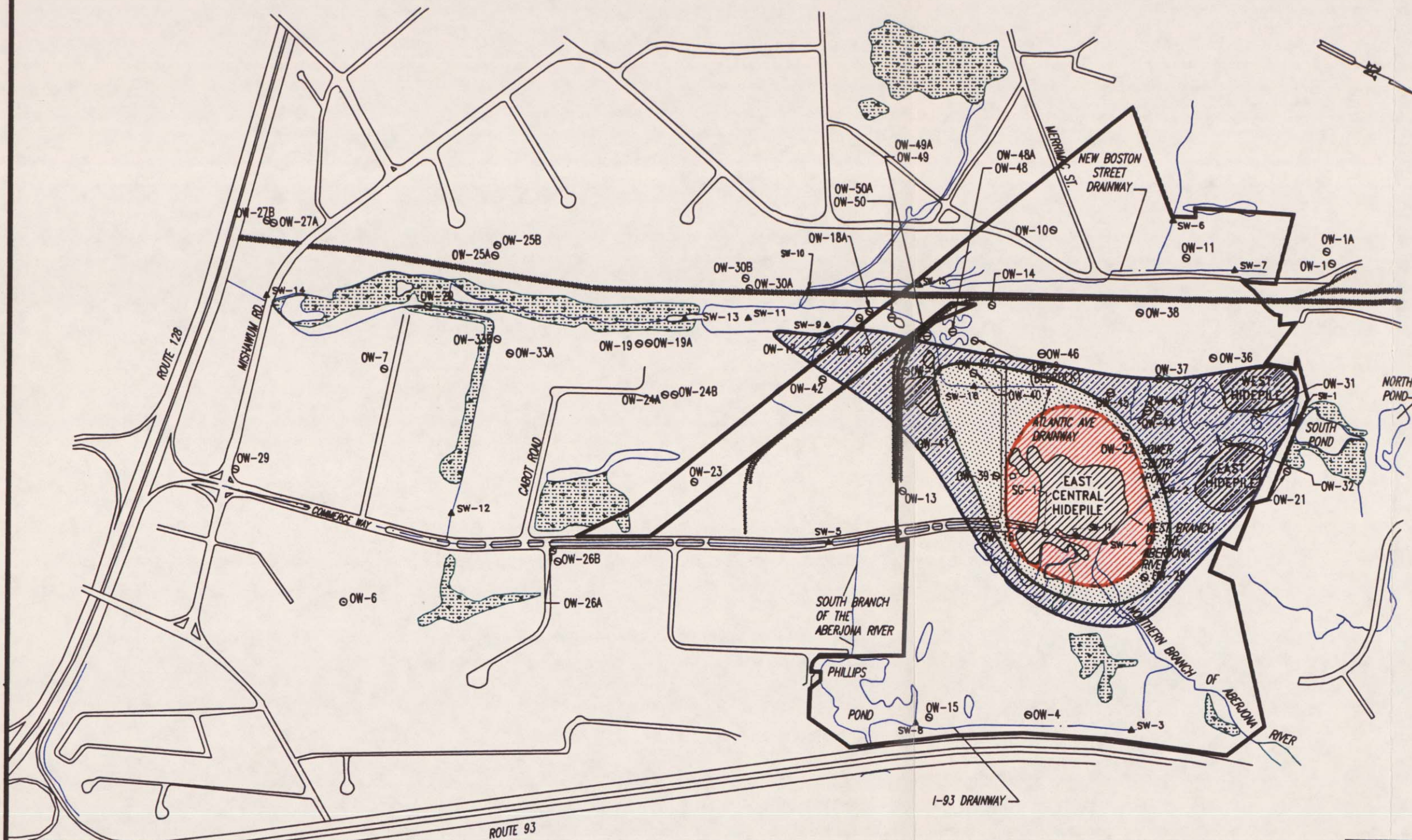THE PRESENCE OF As Ⅲ

Original includes color coding.

PREPARED FOR:

INDUSTRI-PLEX REMEDIAL TRUST

ROUX
ROUX ASSOCIATES, INC.
ENVIRONMENTAL CONSULTING
& MANAGEMENT

COMPILED BY:	J.Y.	DATE:	05/91	FIGURE
PREPARED BY:	R.P./C.L.	SCALE:	AS SHOWN	
PROJECT MANAGER:	T.B.	REVISION:	0	52
PROJECT NO.		06609D		

0'   800'   1600'
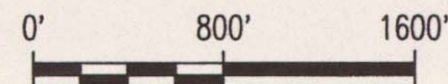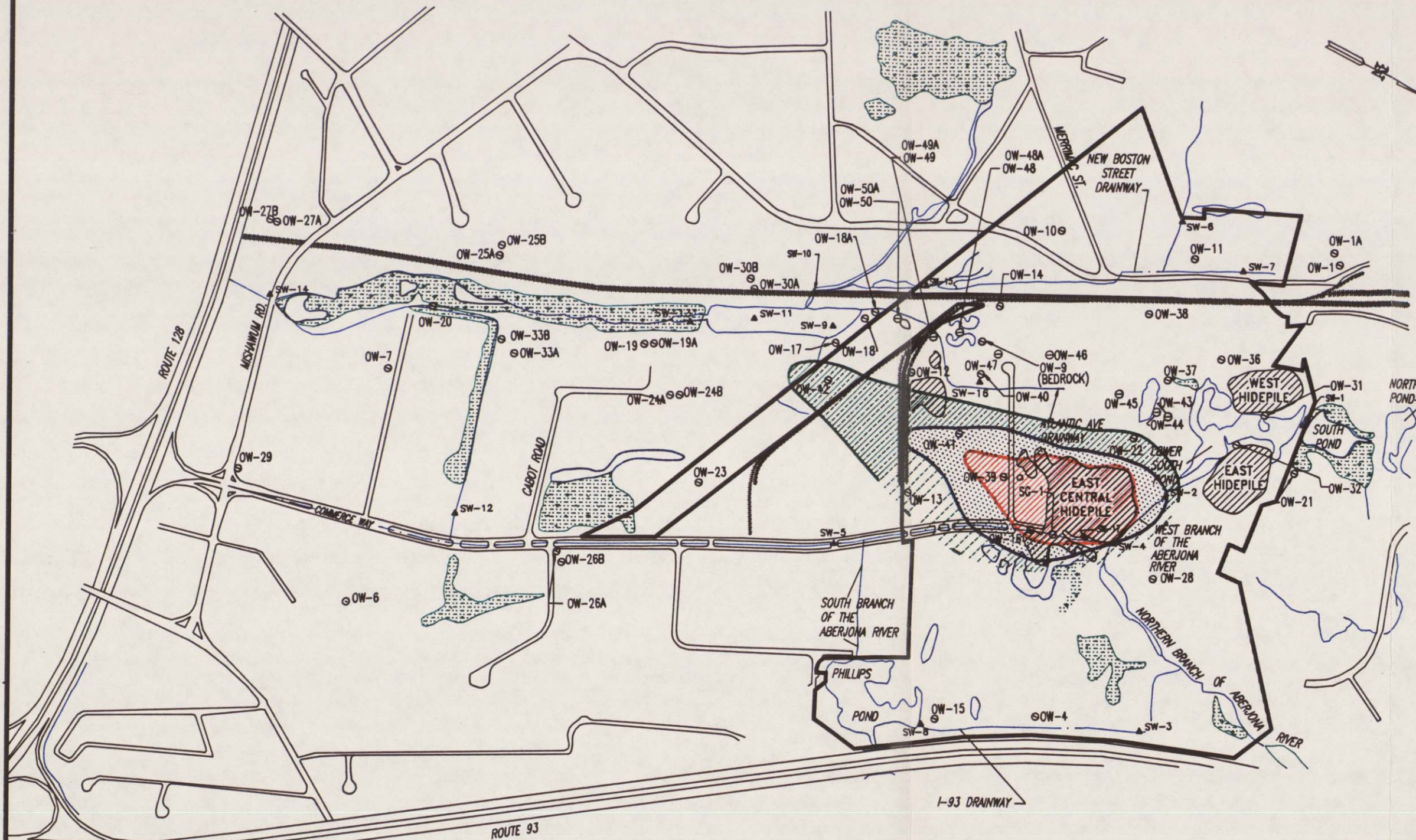
EXPLANATION

▨	> 4 mg/L
▨	1–4 mg/L
☐	0.5–1 mg/L
▨	WETLANDS AREA

NOTE: BASED ON GSIP DATA PROVIDED IN APPENDIX C

TITLE:

CONCENTRATION OF
TOTAL PHOSPHOROUS
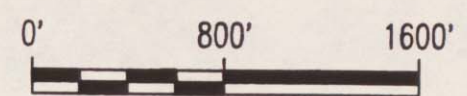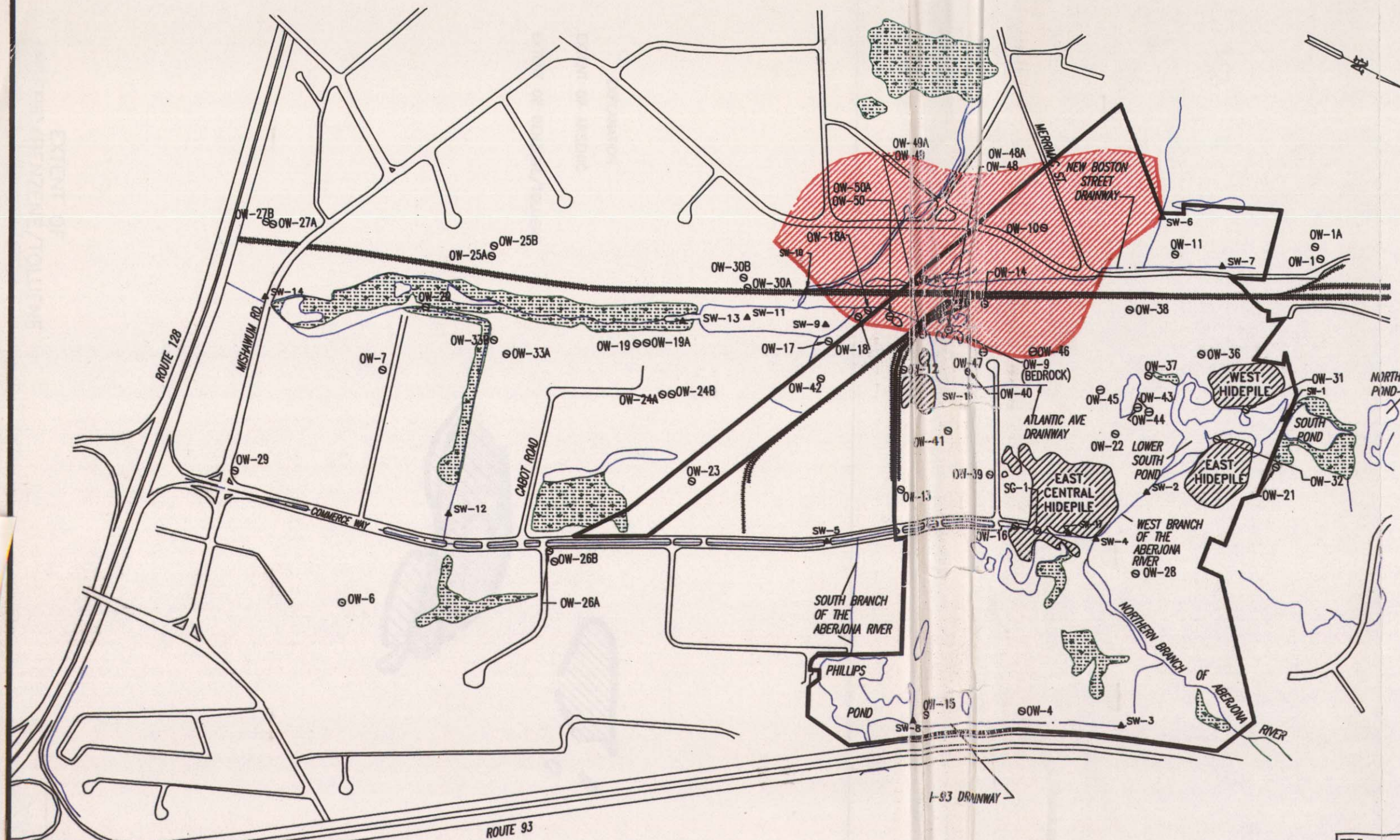IN GROUND WATER

Original includes color coding.

PREPARED FOR:

INDUSTRI–PLEX REMEDIAL TRUST

ROUX
ROUX ASSOCIATES, INC.
ENVIRONMENTAL CONSULTING
& MANAGEMENT

COMPILED BY:	J.Y.	DATE:	05/91	FIGURE
PREPARED BY:	R.P./C.L.	SCALE:	AS SHOWN	
PROJECT MANAGER:	T.B.	REVISION:	0	53
PROJECT NO.		06609D		

0'   800'   1600'

EXPLANATION

CONCENTRATION OF SULFATE

▨ (red hatch)	> 250 mg/L
▦ (dotted)	60–250 mg/L
▢ (white)	< 60 mg/L
▨ (wetland)	WETLAND AREAS

NOTE: BASED ON GSIP DATA PROVIDED IN APPENDIX C

TITLE:

CONCENTRATION OF
SULFATE
IN GROUND WATER

Original includes color coding.

PREPARED FOR:

INDUSTRI—PLEX REMEDIAL TRUST

COMPILED BY:	J.Y.	DATE:	05/91	FIGURE
PREPARED BY:	R.P./C.L.	SCALE:	AS SHOWN	
PROJECT MANAGER:	T.B.	REVISION:	0	54
PROJECT NO.			06609D	

0'   800'   1600'

EXPLANATION

CONCENTRATION OF CHROMIUM

- > 150 ug/L
- 100–150 ug/L
- 50–100 ug/L
- < 50 ug/L
- WETLAND AREAS

NOTE: BASED ON GSIP DATA PROVIDED IN APPENDIX C

TITLE:

CONCENTRATION OF
TOTAL CHROMIUM
IN GROUND WATER

Original includes color coding.

PREPARED FOR:

INDUSTRI—PLEX REMEDIAL TRUST

ROUX
ROUX ASSOCIATES, INC.
ENVIRONMENTAL CONSULTING & MANAGEMENT

COMPILED BY:	J.Y.	DATE:	05/91	FIGURE
PREPARED BY:	R.P./C.L.	SCALE:	AS SHOWN	
PROJECT MANAGER:	T.B.	REVISION:	0	55
PROJECT NO.	06609D			

EXPLANATION

pH

☒ < 6.0

☐ > 6.0

▦ WETLAND AREAS

NOTE: BASED ON GSIP DATA PROVIDED IN TABLE 3-7

TITLE:				
pH OF GROUND WATER				
Original includes color coding.				
PREPARED FOR:				
INDUSTRI−PLEX REMEDIAL TRUST				
ROUX ROUX ASSOCIATES, INC. ENVIRONMENTAL CONSULTING & MANAGEMENT	COMPILED BY: J.Y.	DATE: 05/91	FIGURE	
	PREPARED BY: R.P./C.L.	SCALE: AS SHOWN		
	PROJECT MANAGER: T.B.	REVISION: 0	56	
	PROJECT NO. 06609D			
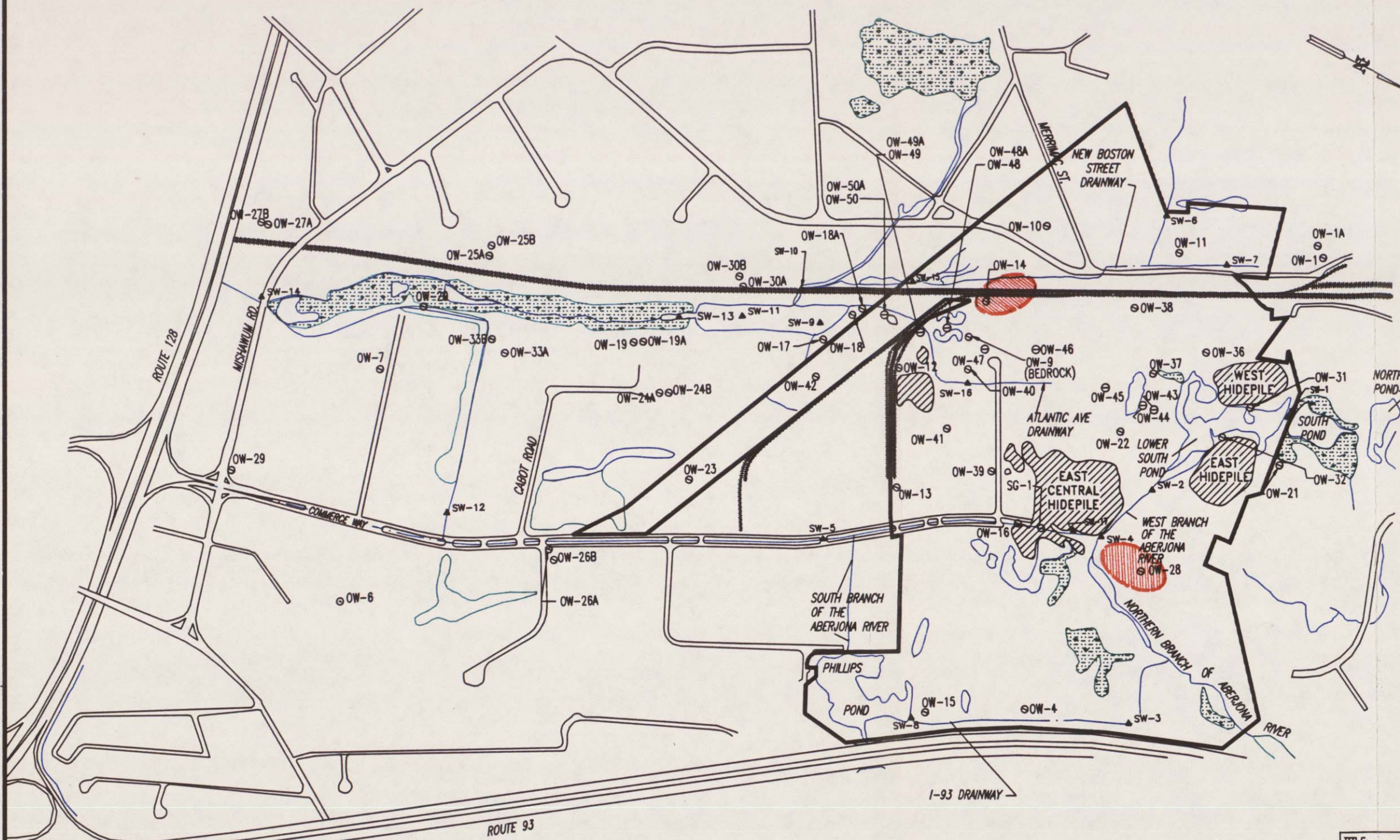
EXPLANATION

CONCENTRATION OF LEAD

▨	> 50 ug/L
☐	< 50 ug/L
▦	WETLANDS AREAS

NOTE: BASED ON GSIP DATA PROVIDED IN APPENDIX C

TITLE:

CONCENTRATION OF
TOTAL LEAD
IN GROUND WATER

Original includes color coding.

PREPARED FOR:

INDUSTRI−PLEX REMEDIAL TRUST

0'   800'   1600'

ROUX
ROUX ASSOCIATES, INC.
ENVIRONMENTAL CONSULTING
& MANAGEMENT

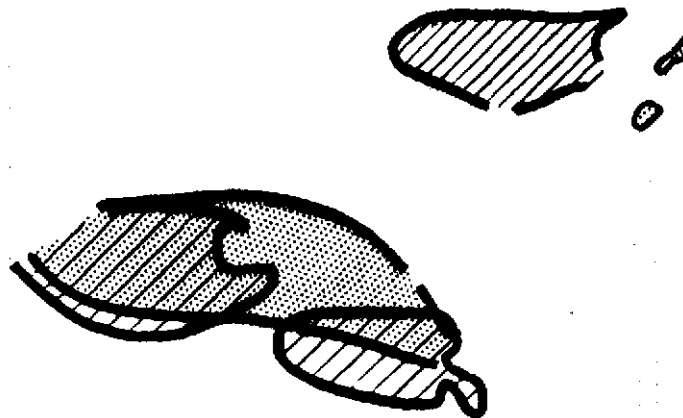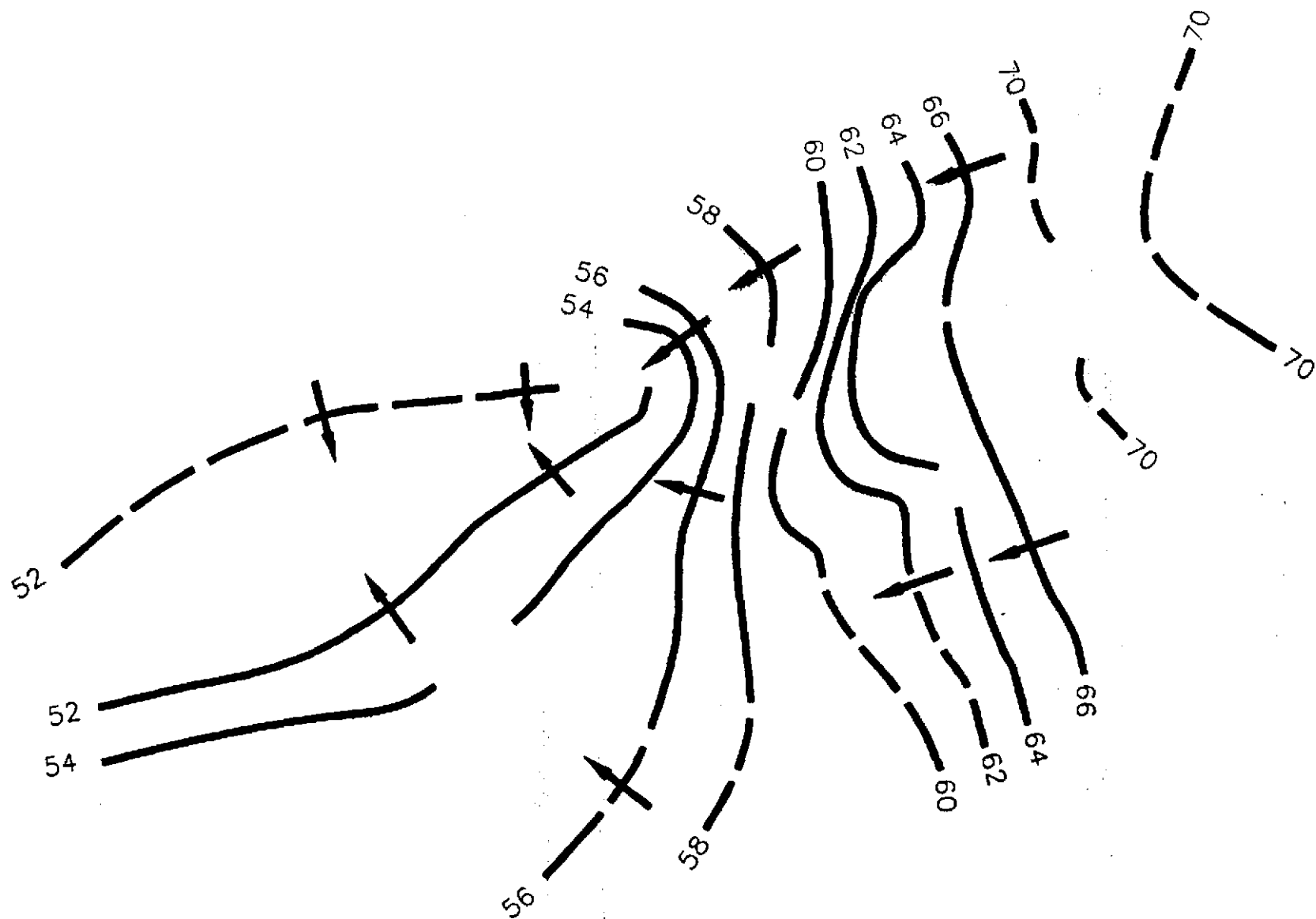| COMPILED BY:	J.Y.	DATE:	05/91	FIGURE
PREPARED BY:	R.P./C.L.	SCALE:	AS SHOWN	
PROJECT MANAGER:	T.B.	REVISION:	0	57
PROJECT NO.		06609D		

EXPLANATION

EXTENT OF ARSENIC
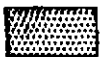
EXTENT OF BENZENE/TOLUENE

EXTENT OF
ARSENIC/BENZENE/TOLUENE
IN GROUND WATER
OVERLAY-3

ELEVATION OF
THE WATER TABLE
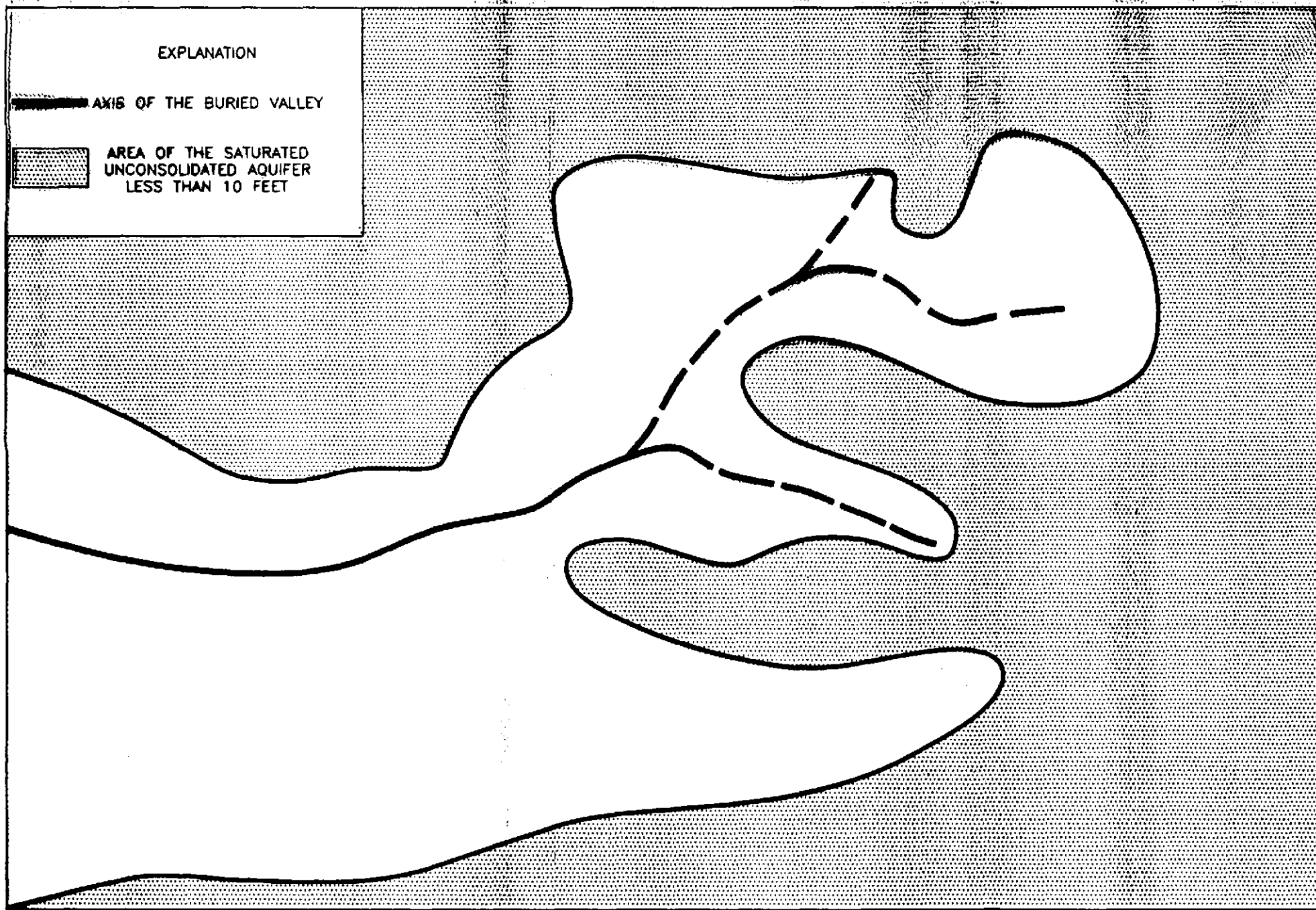MAY 13, 1991

OVERLAY-2

Original includes color coding.
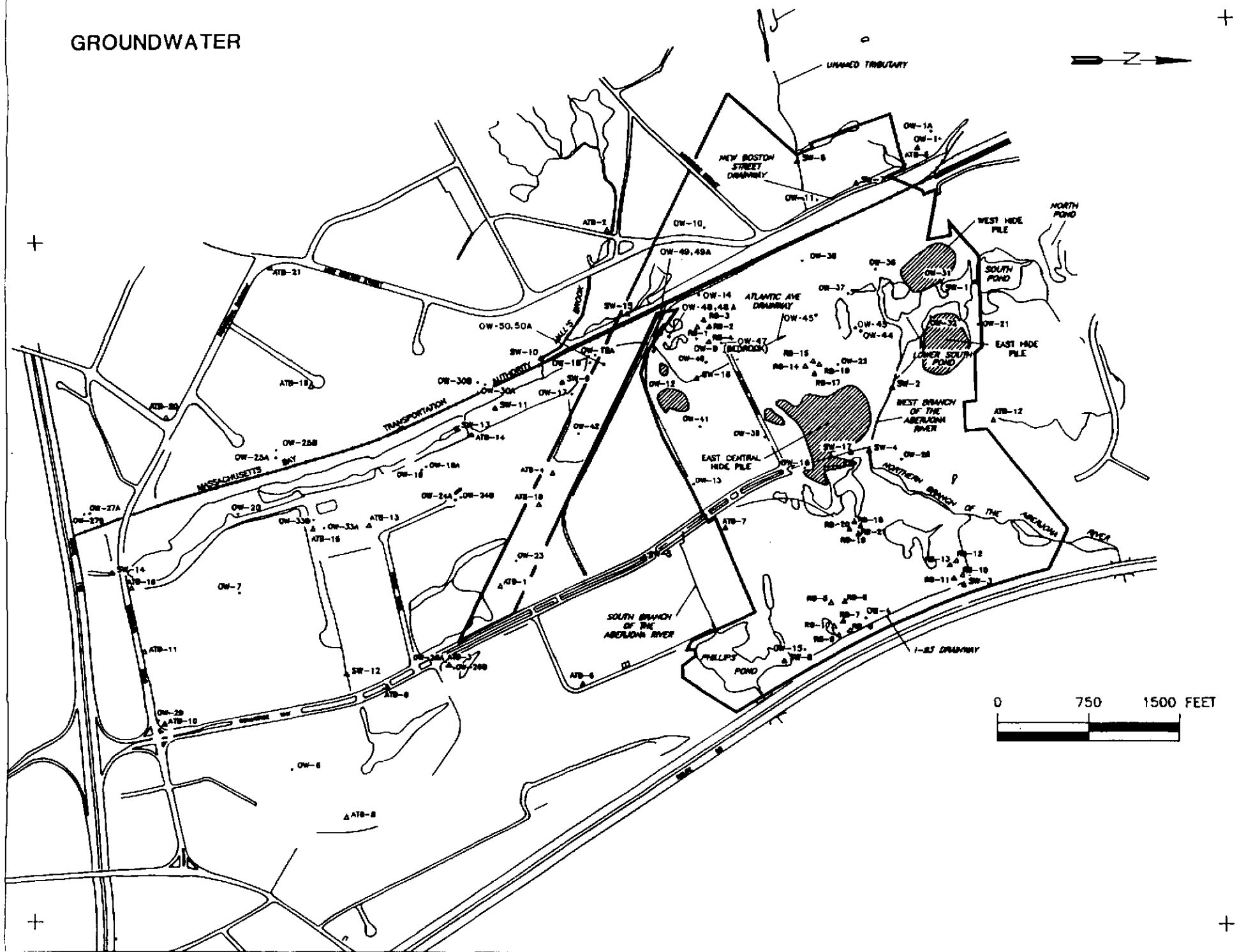
EXPLANATION

AXIS OF THE BURIED VALLEY

AREA OF THE SATURATED
UNCONSOLIDATED AQUIFER
LESS THAN 10 FEET

Original includes color coding.

AREAL EXTENT OF THE
AQUIFER AND AXIS OF
THE BURIED VALLEY
OVERLAY-1

GROUNDWATER

UNNAMED TRIBUTARY

NEW BOSTON
STREET
DRAINWAY

NORTH
POND

WEST HIDE
PILE

SOUTH
POND

ATLANTIC AVE
DRAINWAY

EAST HIDE
PILE

LOWER SOUTH
POND

WEST BRANCH
OF THE
ABERJONA
RIVER

EAST CENTRAL
HIDE PILE

NORTHERN BRANCH OF THE ABERJONA RIVER

TRANSPORTATION AUTHORITY

MILLS BROOK

MASSACHUSETTS

SOUTH BRANCH
OF THE
ABERJONA RIVER

PHILLIP'S
POND

I-93 DRAINWAY

| 0 | 750 | 1500 FEET |

GROUNDWATER

AXIS OF THE BURIED VALLEY

AREA OF THE SATURATED
UNCONSOLIDATED AQUIFER
LESS THAN 10 FEET

EXPLANATION

EXTENT OF ARSENIC

EXTENT OF BENZENE/TOLUENE

0   750   1500 FEET

EXTENT OF
ARSENIC/BENZENE/TOLUENE
IN GROUND WATER
OVERLAY-2

ELEVATION OF
THE WATER TABLE
MAY 13, 1991
OVERLAY-2

AREAL EXTENT OF THE
AQUIFER AND AXIS OF
THE BURIED VALLEY
OVERLAY-1

Original includes color coding.

EXTENT OF
ARSENIC AND BENZENE IN
STREAM SEDIMENTS

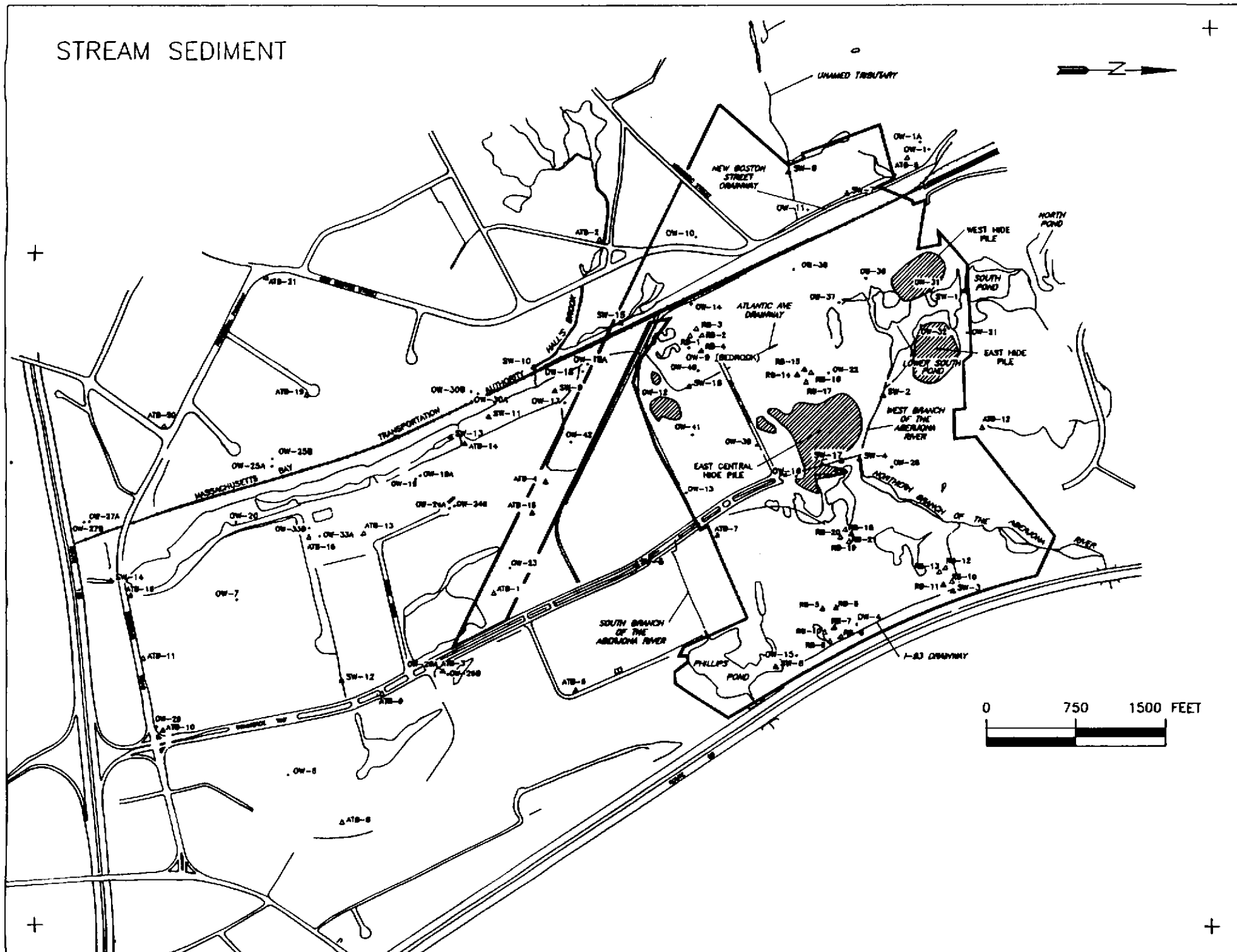OVERLAY-4

Original includes color coding.

EXPLANATION

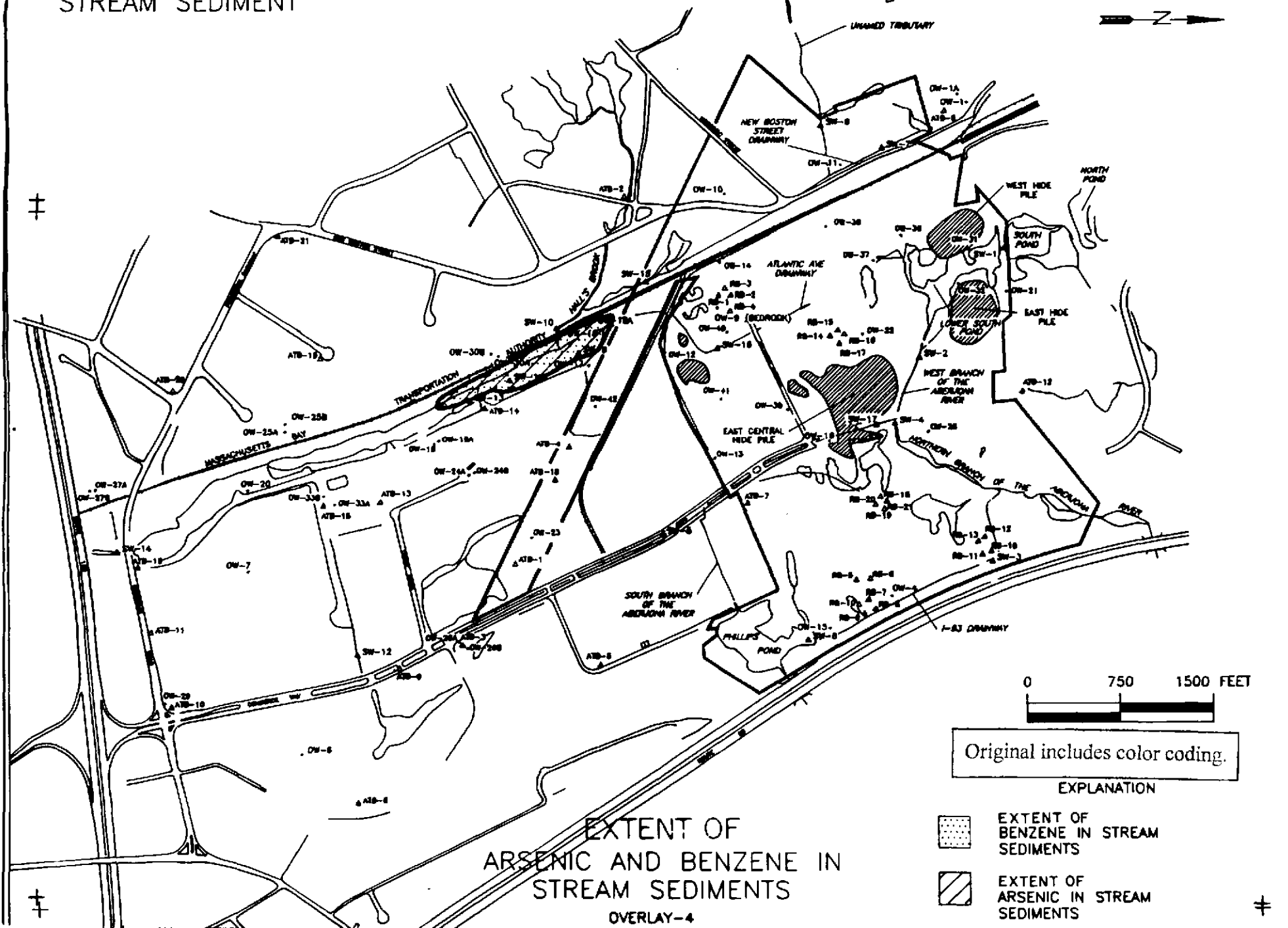EXTENT OF
BENZENE IN STREAM
SEDIMENTS

EXTENT OF
ARSENIC IN STREAM
SEDIMENTS

STREAM SEDIMENT

STREAM SEDIMENT

EXTENT OF
ARSENIC AND BENZENE IN
STREAM SEDIMENTS

OVERLAY-4

Original includes color coding.

EXPLANATION

EXTENT OF
BENZENE IN STREAM
SEDIMENTS

EXTENT OF
ARSENIC IN STREAM
SEDIMENTS

0   750   1500 FEET